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Technical Memorandum No. 33-272

Semiannual Review of

Research and Advanced Development

July 1, 1965 to December 31, 1965

Volume II. Supporting Research and Technology for the Office of Advanced Research and Technology National Aeronautics and Space Administration

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

January 31,1966

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NOTE

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PREFACE

This document is prepared under the direction of the Office of Research and Advanced Development of the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

The Semiannual Review of Research and Advanced Development is published in three volumes directed to the appropriate NASA funding offices:

Volume I	Supporting Research and Technology for the Office of Space Sciences and Applications
Volume II	Supporting Research and Technology for the Office of Advanced Research and Technology
Volume III	Supporting Research and Technology for the Office of Tracking and Data Acquisition (New Systems and Spacecraft Subsystems)

This issue reports progress for the period of July 1, 1965 to December 31, 1965, Fiscal Year 1966. The preceding issue, for the period of January 1 to June 30, 1965, was published as JPL Technical Memorandum 33-243.

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INTRODUCTION

This volume contains a review of all supporting research and technology in progress at the Jet Propulsion Laboratory during the period July 1, 1965 to December 31, 1965, under the direction of the Office of Research and Advanced Development, for the Office of Advanced Research and Technology.

The work units are arranged in numerical sequence by NASA code in each subject section. To locate a desired unit, refer to the Table of Contents under the appropriate heading.

NUCLEAR ELECTRIC SYSTEMS (120)

ELECTRIC PROPULSION (120-26)

ELECTRIC PROPULSION APPLICATIONS STUDIES
NASA Work Unit 120-26-04-01-55
JPL 320-60101-2-3830
D. J. Kerrisk

OBJECTIVE

The long range objectives of this unit are twofold. First is the identification and investigation of problems arising in the integration of available electric thrustor subsystems into a spacecraft propulsion system. The second objective is the evaluation of the effect on interplanetary spacecraft design and performance caused by the incorporation of electric propulsion systems, and the investigation of interface problems arising between the subsystems of such a spacecraft, and between the spacecraft and the launch vehicle and space environments. The objectives of the current fiscal year are (1) to fabricate and test a mercury zero-gravity feed system, (2) to integrate and test this feed system with a mercury electron-bombardment ion engine, flight-weight power conditioning system and closed-loop control system, (3) to design a cluster of such engines for fabrication and testing during FY 1967, (4) to evaluate the cosmic dust and micrometeoroid environments and their effect on large solar panel arrays on interplanetary spacecraft, (5) to analyze the 1965 NASA prospectus and evaluate the applicability of solar-powered electric propulsion to the missions proposed therein, and (6) to revise and update the trajectory analysis programs to reflect the needs of solar-electric spacecraft.

ELECTRIC PROPULSION SYSTEMS

Because of a requirement of the solar-electric program (NASA Work Unit 120-26-04-03), attention was shifted from cesium to mercury systems. A zero-gravity mercury feed system was designed and test components fabricated. This system is shown schematically in Fig. 1, and is described in Ref. 1 and 2. A more complete theoretical analysis and description of all test results is being presented in Ref. 3. The feed system has a projected specific weight of 2.5 lb/kw and a power requirement of about 25 w. In tests to date it has given every indication of simple and reliable operation.

Design of a complete propulsion system module – integrating the feed system with the engine, power conditioning, and controls – is essentially complete, and fabrication will start during the current quarter. This module, shown conceptually in Fig. 2, is to be a prototype for a cluster of modules to be fabricated and tested during FY 1967. The cluster experiment is necessary to demonstrate the feasibility of propellant switching from engine to engine in an electrically isolated feed system, and of power matching the propulsion system load to the solar panel output, while maintaining thrust vector control.

To prepare for the clustered system tests, a new vacuum chamber, 7-1/2 in. in diameter and 15 in. long, is being installed in the electric propulsion laboratory. The contract for the fabrication of this chamber and its cold wall liner is presently being negotiated. It is anticipated this vacuum system will be installed and ready for use early in FY 1967.

Work on the analysis of the plasma in an electron bombardment engine was concluded during the report period. As part of the investigation, an ion engine employing a reversed arc configuration, i.e., with an annular cathode and central anode, was fabricated and tested. This thrustor is shown in Fig. 3. It was found that in this configuration significant improvement in plasma uniformity could be achieved. In several runs, plasma density variations from center to periphery were less than a factor of 2, compared to a factor of 10 usually observed in conventional engines. The engine and its performance are described in Ref. 4 and 5. The overall results of the plasma study in cesium and mercury engines are being presented in Ref. 6.

ELECTRIC SPACECRAFT STUDIES

Much of the work in the area of spacecraft studies was redirected during the report period from nuclear powered spacecraft to solar powered spacecraft. This redirection reflects the impact that current solar-electric feasibility studies, contracted under NASA Work Unit 120-26-04-03, are having on the possibility of early electric propulsion missions and was anticipated when the FY 1966 task was initially formulated.

Specifically, all studies of nuclear-electric spacecraft beyond completion of the initial radiator configuration study have been dropped. The results of the three-loop radiator configuration study were presented in Ref. 7. The radiator calculation computer program was discussed in some detail in Ref. 8. Configuration layouts for the two loop system and for the shielding study were completed, but no further work is being done on this.

Two specific areas in solar electric propulsion were attacked during this period. First was a study of the effect of the cosmic dust and micrometeoroid environments on large solar panel arrays. To accomplish this and to establish criteria for experimental investigations, a study of cosmic dust was initiated. One part of this investigation is reported in Ref. 9. A previous micrometeoroid investigation is being updated by making use of the Mariner IV data to modify the micrometeoroid model. Also, a new computer program is under development to correlate Mariner IV data with existing cosmic dust models to attempt to get a more realistic picture of the interplanetary hazard. These models will then be combined with the trajectory studies to determine anticipated solar panel micrometeoroid protection requirements, and degradation characteristics of the panels due to erosion by cosmic dust. Both these effects could have considerable influence on solar-electric feasibility.

The second area is an analysis of the NASA 1965 prospectus, with an emphasis on high energy missions, to investigate the applicability of solar-electric propulsion to the missions designated as of interest to OSSA. An important part of this task is compiling booster information on all available and proposed boosters and upper stages so an accurate and realistic comparison of chemical and solar-electric capabilities can be made. Of particular interest are smaller boosters, such as the Atlas-Agena, with and without high energy kick stages. Shroud and center of gravity constraints, as well as performance data, are being tabulated.

In addition, the present trajectory program is being revised to include the effects of Earth gravitation on the heliocentric trajectory. The revised trajectory data shows a significant improvement in solar-electric performance capability, and a major effort during the coming quarter will be the updating of all the previous performance analyses to reflect this improvement.

REFERENCES

1. Masek, T. D., and Kerrisk, D. J., "Zero Gravity Feed System for Mercury Ion Engines," JPL SPS 37-33, Vol. IV, June 30, 1965.

2. Masek, T. D., and Kerrisk, D. J., "Zero Gravity Feed System for Mercury Ion Engines," JPL SPS 37-35, Vol. IV, October 31, 1965.

3. Kerrisk, D. J., and Masek, T. D., "A Zero-Gravity Mercury Propellant Feed System," to be given at the 5th AIAA Electric Propulsion Specialists Conference in San Diego, California, March 7-9, 1966.

4. Masek, T. D., "Plasma Investigation in a Reverse Current Electron Bombardment Ion Engine," JPL SPS 37-36, Vol. IV, December 31, 1965.

5. Masek, T. D., "Plasma Investigation of a Reversed Current Electron Bombardment Ion Engine," to be presented at the 5th AIAA Electric Propulsion Specialists Conference in San Diego, California, March 7-9, 1966.

6. Masek, T. D., "Plasma Characteristics of the Electron Bombardment Ion Engine," to be given at the 2nd International Conference on Electron and Ion Beam Science and Technology to be held in New York, April 17-20, 1966.

7. Volkoff, J. J., and Womack, J. R., "Preliminary Investigations to Determine Nuclear-Electric Spacecraft Configurations for High Energy Missions," AIAA Paper No. 65-413, given at the AIAA Annual Meeting, San Francisco, California, July 1965.

8. Volkoff, J. J., "A Design for an All Liquid Heat Rejection Radiator System," JPL SPS 37-36, Vol. IV, December 31, 1965.

9. Volkoff, J. J., "Testing of Erosion Rates by Cosmic Dust Particles," presented at the American Vacuum Society Annual Meeting, Boston, Massachusetts, September 28 - October 1, 1965.

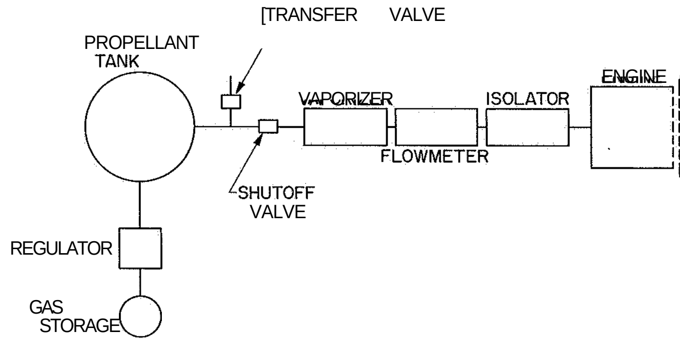

Fig. 1. Zero-gravity feed system

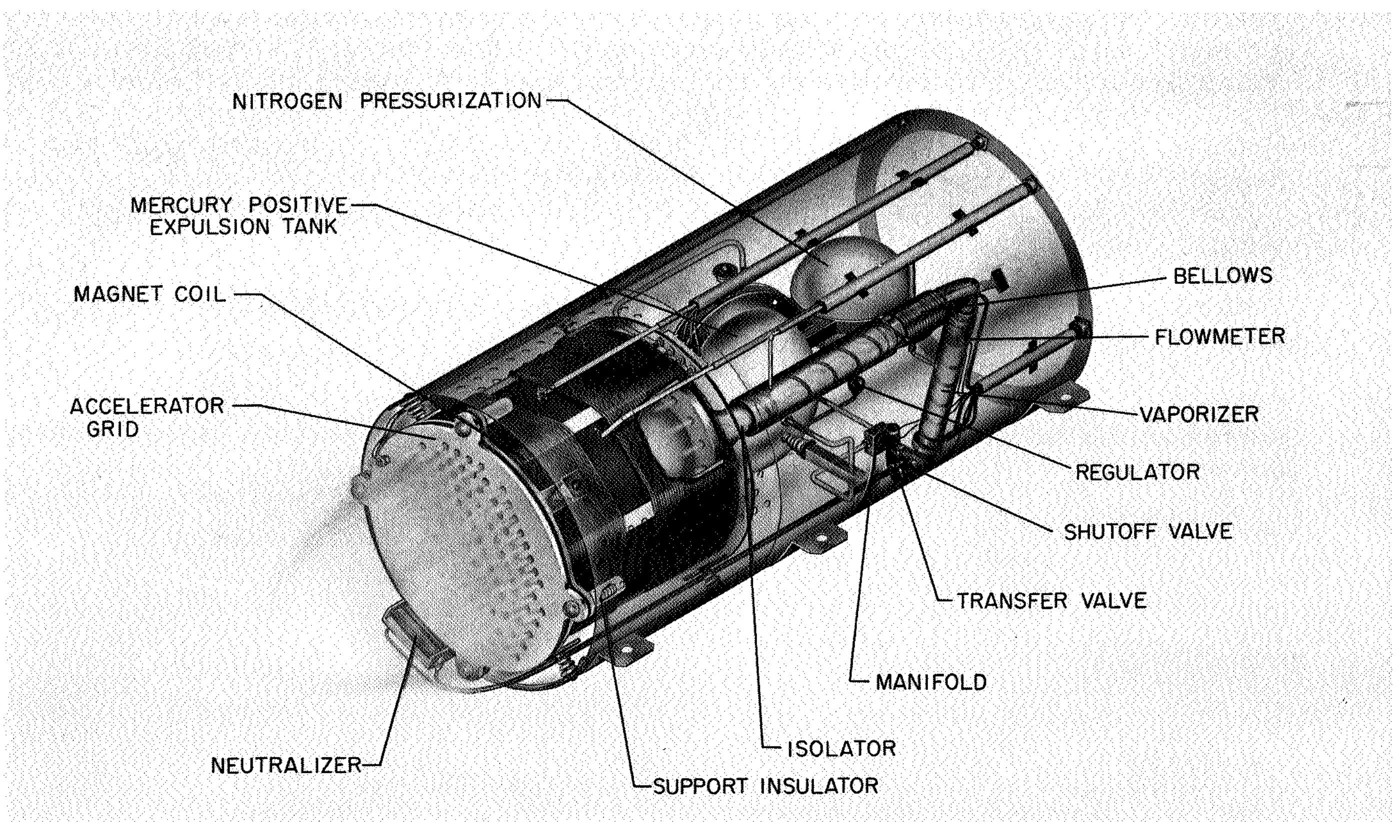

Fig. 2. Mercury positive expulsion system

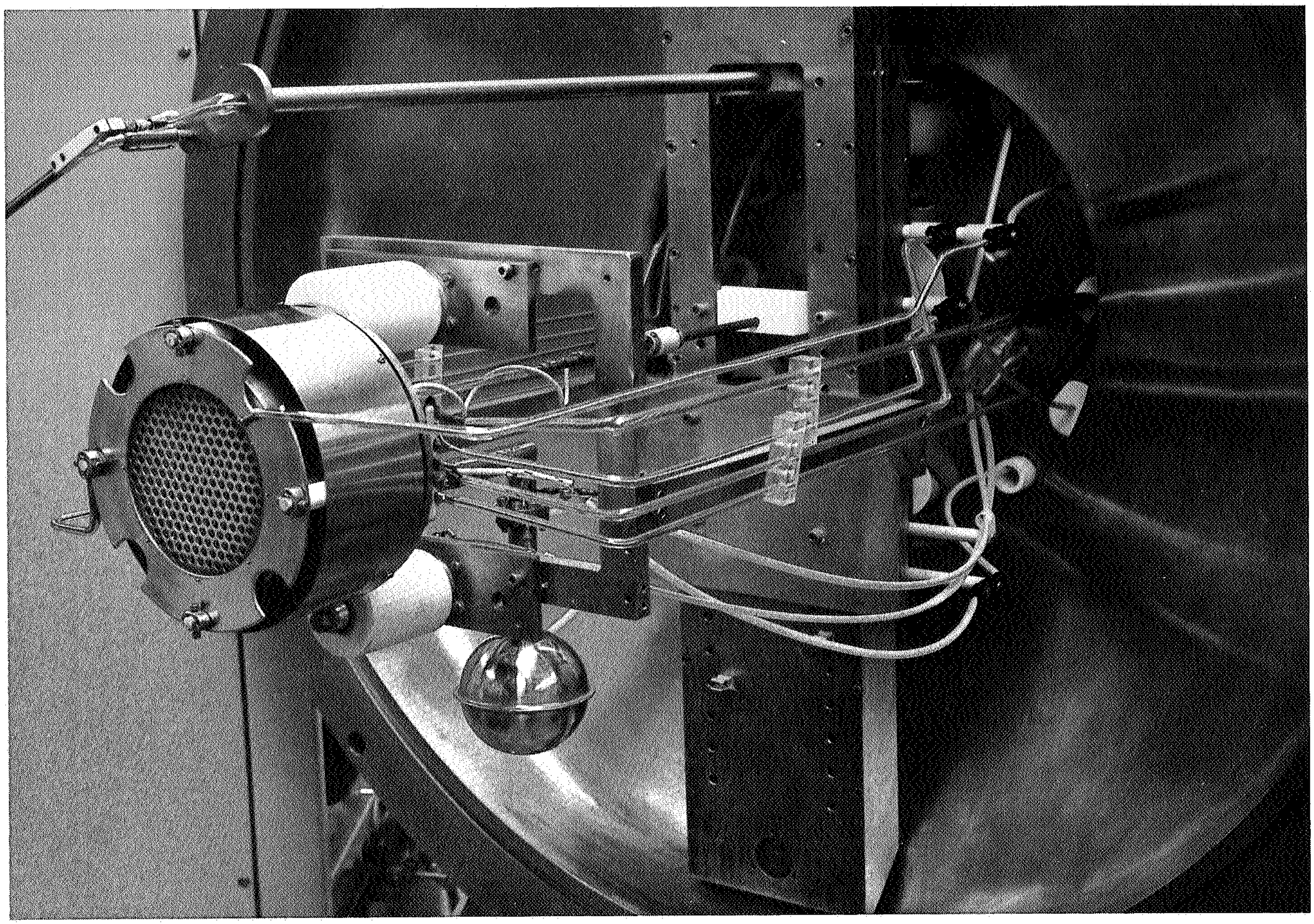

Fig. 3. Ion engine thruster

SOLAR-ELECTRIC PROPULSION STUDY
NASA Work Unit 120-26-04-03-55
JPL 320-60501-2-3830

J. W. Stearns

OBJECTIVE

With the use of current state-of-the-art component technology to study the performance and potential application of lightweight deployable solar arrays and electric propulsion subsystems to spacecraft, the objective of this work unit is: (1) to establish the feasibility of large deployable, solar arrays weighing 50 lb/kwe or less, at power levels in excess of 5 kw; (2) to establish the feasibility of electric propulsion systems weighing 25 lb/kwe or less, including power conditioning, controls, feed system, tankage and thrustors, and evaluate the lifetime demonstration of ion engines, to consider their suitability for spacecraft mission applications, performing 500-hr tests of electric propulsion systems; and (3) through analysis and conceptual design studies, to show the feasibility of integrating large solar arrays and electric propulsion into mission spacecraft, expanding mission analysis capability and scope to include electric propulsion system sizing and reliability tradeoffs, comparisons with chemical spacecraft, and the effects of 3 dimensions on selected trajectories.

LARGE SOLAR ARRAY FEASIBILITY STUDY

This portion of the solar-electric study was accomplished under NASA Work Unit 123-33-01-02. Contracted to the Boeing Company, configuration and design studies have been completed. The feasibility of achieving 50 lb/kwe for power levels up to 50 kwe has been adequately shown in detailed design analyses. Sample panels have demonstrated substrate construction, solar cell mounting, and interconnect techniques. Scale array models have been built and demonstrated.

A final report covering the results of the solar array studies has been submitted (Ref. 1), and the contractor will brief the joint NASA/USAF review committee on January 19, 1966. These studies are expected to be the basis of a full-scale panel development contract to be initiated in the next reporting period.

ELECTRIC PROPULSION SYSTEMS DEVELOPMENT

Development of electric propulsion systems, including the evaluation of ion engine life testing and system feasibility test demonstration, is continuing. Flight-design ion engine life is now extrapolated to 10,000 hr, and several unit tests have exceeded 2000-hr demonstration. Life test data to 4000 hr is expected during the next report period. Under JPL Contract (this work unit) Hughes Aircraft Company will provide the demonstration in a 500-hr test of a complete propulsion system module, including thrustor, zero-gravity feed system, flight-type power conditioning, and closed loop controls. The test is to demonstrate that the module can be built to a specific weight of less than 25 lb/kw, meeting all performance requirements of a solar-electric spacecraft including the redundancy necessary to system reliability.

POWER CONDITIONING AND CONTROLS

A breadboard power conditioning system has been built and was successfully tested with a liquid pool cathode engine in December, 1965. The system included the main drive, the accel, and the arc supplies, but none of the heaters. Failures were simulated, and automatic module replacement was demonstrated. A final design review was held at HAC on December 16, in which permission was given for the fabrication of the prototype system. This system differs from the breadboard system in that the input voltage was lowered to meet the proposed requirements of the NASA-LeRC Sert II program. This required a change in the transistors in the main drive supply, and some rework of the base drive circuits. No outstanding problems have appeared, and fabrication of the power conditioning and control system is anticipated to be completed by February 1, 1966. Delivery to HRL for integration and testing will follow immediately. Subsequently, the initial breadboard system will be modified to bring it to flight configuration. This system will then serve as a backup to the prototype test system.

THRUSTOR AND FEED SYSTEM

The NASA LeRC Sert II thrustor was delivered to HRL in November, 1965. A subsequent modification to the existing contract directed Hughes to perform engine performance tests prior to the contracted 500-hr-system demonstration. This test was initiated on December 29, 1965, and will continue until January 7, 1966. The engine was operated with the HRL zero-gravity feed system, and no problems were observed. In addition, the control system was simulated on an analog computer, using data obtained during the engine and feed system test. The data from this test is still being analyzed; however, initial results indicate the control system will work as designed. After January 7 the test will be discontinued and a modified propellant feed system will be fabricated for the 500-hr test. Preparation for the test will continue into February, with the test currently scheduled to start about February 15, 1966.

SPACECRAFT SYSTEM STUDIES AND MISSION ANALYSIS

Including the award of propulsion system fabrication and 500-hr test demonstration as noted in the previous Semiannual Report (Ref. 2) and Ref. 3, the amount of Hughes Aircraft Company contracting now stands at $815,500. Approximately 50% of this funding has been provided for feasibility studies involving mission performance analysis, propulsion reliability and cost analysis, and spacecraft conceptual design.

A Mars orbiter mission was utilized as a mission model, and the basic parameters of spacecraft design were studied in considerable detail. Both a Saturn IB/Centaur and Atlas/Centaur were considered as launch vehicles, thus spanning a reasonable range of spacecraft weight and power requirements. Feasible spacecraft concepts have evolved from the study of launch configuration constraints, the geometrical considerations of heliocentric flight, and environmental requirements. One of the latest spacecraft concepts is illustrated in Fig. 1 (Ref. 4).

Launched to Earth-escape energy, the solar arrays are deployed and the electric propulsion system operates during heliocentric flight. With emphasis on reliability and versatility, the solar arrays and propulsion subsystems are of modular construction, making it possible for one basic spacecraft design to be studied for a wide range of missions. A representative heliocentric trajectory is shown in Fig. 2 for a 300-day Mars mission. Thrust angle is held constant with respect to the Sun-probe line, and thrust magnitude decreases as the spacecraft moves away from the Sun.

The solar-electric spacecraft arrives at Mars with a small approach velocity (less than 1 km/sec). The electric propulsion subsystem and the majority of the solar array are no longer useful and are jettisoned prior to firing the chemical retro-rocket that injects the final spacecraft into orbit around Mars.

Structural analysis has been accomplished for spacecraft in both the stowed-launch and the deployed condition. The Hughes and Boeing studies were closely coordinated for this effort. Launch vehicle center-of-gravity constraints have an important effect on spacecraft design. While it is structurally desirable to provide hinging of the solar panels at the base of the spacecraft, this requires the center of mass of the spacecraft when the panels are extended will be lower than that during launch. The electric propulsion thrust must be directed through the deployed center of mass, and the engines will therefore be fairly close to the plane of the solar array. The angle of the thrust vector then becomes quite critical as well as any divergence of the plasma beam.

Power conditioning and propulsion controls, even at high efficiency, are handling such large power levels that thermal design is of major importance. Modular panel construction in the concept shown has provided for mounting on the spacecraft for adequate heat radiation. Relationships between radiation surfaces, guidance and control sensor view angles, communication patterns, and the like have been studied for the Mars mission model in sufficient detail to assure that no basic problems exist. Additional work has started for better definition of all missions of interest to electric propulsion.

An additional 8000 hr of engineering study for the remainder of FY 1966 is under negotiation at this time. This work is required for the investigation of specific engineering problems for additional understanding of potential spacecraft performance. Basic support will be needed for advanced studies being initiated at JPL. This includes propulsion system performance and systematic errors, attitude control mechanization, telecommunications trades, and propulsion system-induced spacecraft environments. A new three-dimensional, n-body computer program is to be written for increased adequacy of handling low-thrust solar-electric trajectory studies, and reliability studies are to be extended.

REFERENCES

1. Boeing Final Report #D2-23942-5, Fabrication Feasibility Study of a 20 Watt Per Pound Solar Cell Array, December 1965.
2. JPL TM 33-243, Vol. I, II, III.
3. Phase I Report-Design, "Ion Engine Modular Power Conditioning and Control System," Contract #951144, July 2, 1965.
4. Hughes Aircraft Corporation Final Report #SSD 50094R, Solar Powered Electric Propulsion Spacecraft Study, December 1965.

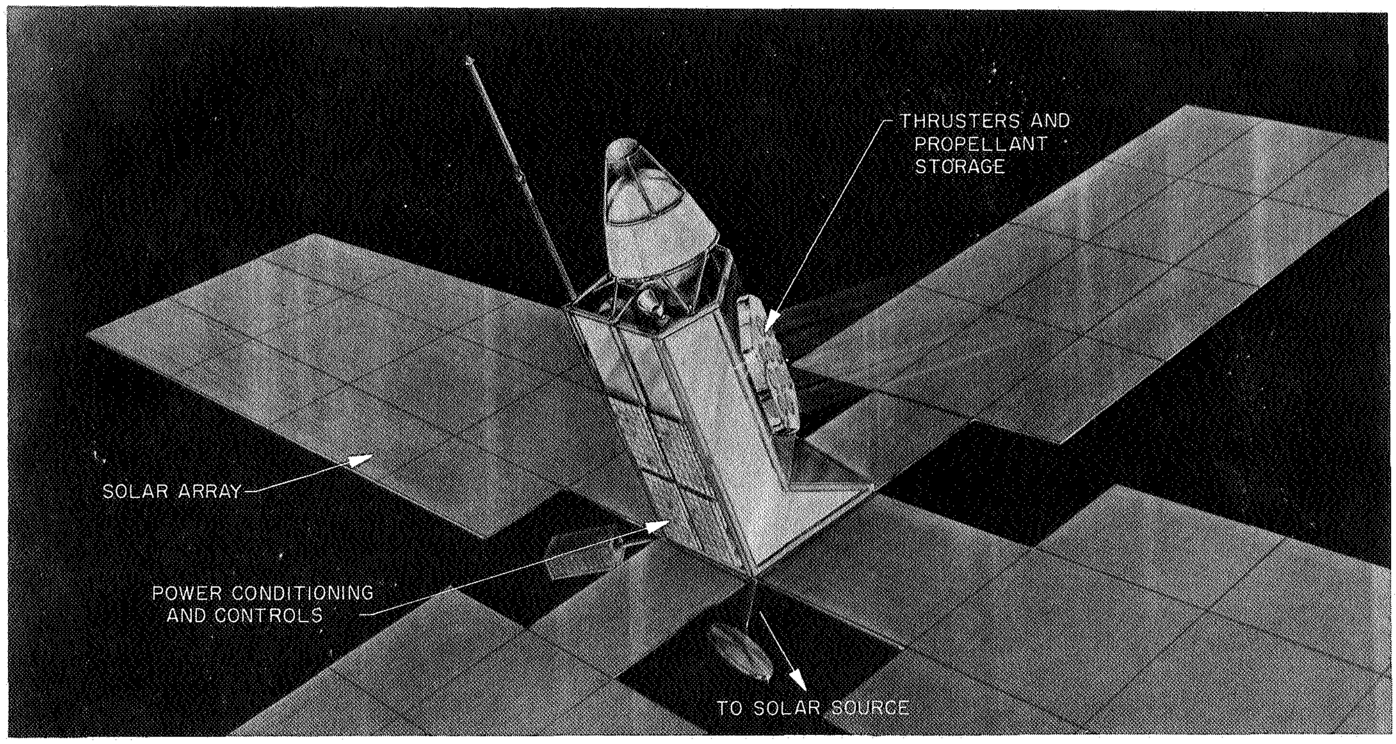

Fig. 1. Electric propulsion spacecraft

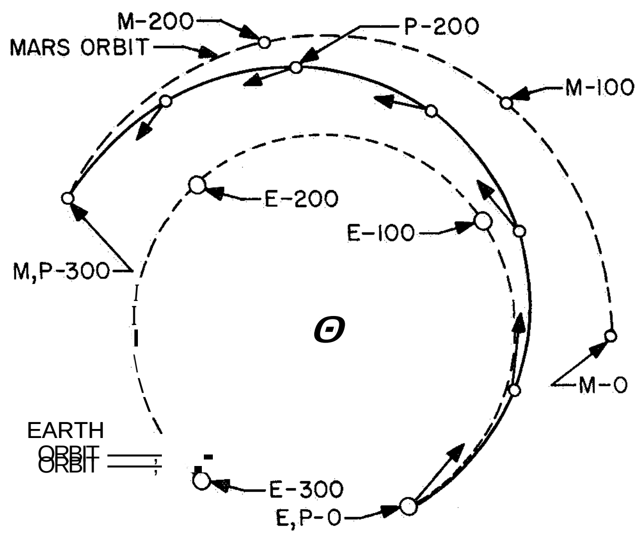

Fig. 2. Trajectory for 300-day Mars mission

NUCLEAR ELECTRIC POWER (120-27)

NUCLEAR SYSTEM DEFINITION STUDIES

NASA Work Unit 120-27-06-01-55
JPL 320-70101-2-3420
L. Selwitz

OBJECTIVE

The objectives of this program are to define the problems and evaluate the technology required for radioisotope thermoelectric generators for lunar and planetary missions. Factors to be considered include: reliability, weight, impact resistance, temperature control and heat rejection, radiation interfaces, and intra-power system interfaces.

THERMOELECTRIC MODULE LIFE AND PERFORMANCE TESTING

This effort is intended to evaluate the state of the art of current thermoelectric hardware and to determine the long life performance characteristics of thermoelectric devices.

Test System

Four high-vacuum test chambers have been assembled to accommodate four test units. Ultimate pressures as low as 10^{-7} torr have been achieved in the chambers. Control of the test units and monitoring of equipment is accomplished in two control and instrumentation consoles, each of which handles two test units. The control consoles provide for automatic readout of thermoelectric open circuit voltage, load voltage and current, and short circuit current. In addition, the console monitors coolant flow, generator temperatures, and heater current and voltage input.

Thermoelectric Test Units

Two thermoelectric contracts have been signed. One contract, for an RCA thermoelectric test unit, has been completed and the unit is currently under test in the laboratory. At full temperature, 900°C, it is producing 22 w at 4 v, which is its design specification. The other completed contract is for a Monsanto Research Corporation high temperature thermoelectric generator to be delivered by June 1966. A fourth contract, for two relatively small "SNAP 27" type thermoelectric modules, from Minnesota Mining and Manufacturing (3M), is currently under negotiation.

THERMOELECTRIC FAILURE-MODE TESTING AND ANALYSIS PROGRAM

The objective of this program is to determine the limits of physical and environmental operating conditions beyond which thermoelectric devices will fail. The program will also furnish information on the particular mode of failure.

Test System

Five specific test areas are planned: impact and vibration, sublimation and oxidation, mechanical stress, overtemperature, and electrical overload. The impact and vibration tests will be carried out in the JPL environmental testing facilities. All other tests will be set up in a failure-mode test laboratory contemplated for Building 198.

Procurement action has been initiated for an ultra-high-vacuum system capable of attaining pressures as low as 10^{-11} torr for carrying out sublimation tests.

Test Devices

Procurement has been initiated for thermoelectric failure mode test hardware from RCA, Westinghouse, and 3M. Individual thermoelectric couples are being obtained from RCA and 3M. Tubular thermoelectric modules are being obtained from Westinghouse; they will be tested at impact loads up to 10,000 g.

NUCLEAR REACTOR AND LIQUID METAL SYSTEMS

NASA Work Unit 120-27-06-02-55
JPL 320-70201-2-3830
Jerry P. Davis

OBJECTIVE

The overall objective of this work unit is the advancement of liquid metal and refractory metal technology as applied to nuclear reactor and conversion systems for space power application. The effort is primarily engaged in the construction and operation of a two-loop alkali metal Rankine cycle system, thermionic reactor analysis and evaluation, materials investigations, and a high-temperature nuclear fuels survey.

LITHIUM-BOILING POTASSIUM TEST LOOP

The lithium-boiling potassium test loop has been installed in its chamber and connected to the fill-dump, vacuum, and argon systems. All instrumentation and power inputs to the loop have been completed. The system is presently being outgassed preparatory to initial liquid metal fill.

One problem of interest arose during the final assembly phase. The turbo-alternator stator Dowtherm cooling line is fitted with a concentric stainless steel bellows to permit thermal expansion relative to the columbium case. The end fitting on this bellows is brazed to the case (GE 8400 braze) and developed a small leak. Attempts at local remelting and rebrazing were not successful. Since this end of the turbo-alternator runs at essentially ambient argon temperature (- 300°F) and low pressure, it was decided to attempt an epoxy seal in the local leak area. Five different epoxy mixes were utilized on test joints of columbium to stainless steel to determine adhesion, thermal shock characteristics, and resistance to potassium at 400°F. One compound, Epoxylite #850-9, showed excellent properties in these critical areas, including no detectable potassium attack, and was subsequently used for sealing the existing leak.

After installation of the loop in the chamber, hand rotation of the Byron-Jackson centrifugal pump resulted in a perceptible subbing noise in the vicinity of the hydraulic bearing. This problem has now been rectified by disassembly and reassembly of the motor to impeller shaft and releveling of the pump.

During this period, Geoscience, Ltd. , submitted their final report on the transient and steady-state behavior of the lithium-boiling potassium loop. The report was of excellent quality, and indicated general loop behavior characteristics as previously expected.

It is anticipated that the second half of this fiscal year will primarily be occupied by the accumulation of loop operational data.

MATERIALS

A report on the results of tests on oxidation resistant coatings for refractory metals for application in contaminated inert atmospheres is currently in publication.

Data compiled on nuclear fuels for thermionic applications has been compiled into a classified report and is also currently in publication.

A contract has been negotiated with Battelle Memorial Institute for a survey of high-temperature nuclear fuels to supplement work completed at JPL. The unclassified portion of a literature survey at JPL has been completed, and the work on the classified portion is in progress.

Results of O-ring material compatibility tests with alkali liquid metals have been presented in Ref. 1 and 2.

An electron beam welding facility has been installed and checkout completed. This unit is in operation and is being used for specimen fabrication for investigations of refractory metal interactions in alkali metals.

Specimen testing on mass transfer phenomena in stainless steels exposed to alkali liquid metals has been completed. Evaluation of test specimens has been delayed because of personnel requirements for final assembly and startup of the liquid metal heat transfer loop experiments. It is expected that these results will be available during the next half year and will be published as a JPL report.

Additional work on the effectiveness of various hot trap materials in the prevention of mass transfer in both stainless steels and refractory metals is planned. Specimen fabrication will be initiated during the first quarter of the calendar year.

SURVEY OF INDUSTRY PROPOSED THERMIONIC REACTOR SYSTEMS

The survey of the industry proposed in-pile space thermionic reactor systems was completed. Three technical memoranda were prepared and submitted to NASA's RNP office (Ref. 3, 4, and 5). This completes the general evaluation work. A continuing followup on developments is to be maintained.

STABILITY OF NUCLEAR THERMIONIC SYSTEMS

The general kinetics and stability analysis work on nuclear thermionic systerns continued and system equations are being programmed on the analog computer. The details and objectives of this investigation are explained in Ref. 6. The present phase of this work will be completed during the third quarter of FY 1966. The study is expected to answer general questions on kinetics and stability and to provide design feedback information. A continued analytical evaluation on thermionic systems is maintained. As provided for in FY 1966 budget appropriations a consultant has been requested to assist in the above analysis and in developing appropriate digital computer programs. The computer programming services will be submitted for bidding.

The main objective with the digital computer analysis is to make it feasible to also include spatial effects in addition to time dependence as limited by the analog computer.

During the third quarter of FY 1966, it is planned to initiate a general study on minimum reactor sizes, comparing thermionic, Rankine cycle, and Brayton cycle systems. Tentatively, 50 kw electric net plant output has been selected as an appropriate system power level at which to carry out the comparisons.

The American Nuclear Society 1965 Winter Meeting, November 15-18, 1965, was attended by J. P. Davis and H. Gronroos. Conference Report No. 383-36 (11-22-65) summarizes meeting impressions.

J. P. Davis, H. Gronroos, and W. Phillips attended a NASA Nuclear Thermionic Program Review Meeting August 30, 1965, in Washington, D. C. A review of Section 383 work and opinions was given by the attendees.

H. Gronroos, J. Volkoff, and R. Womack visited Atomics International, Canoga Park, California, on September 8, 1965, to discuss space nuclear power plant shielding problems. A Section 383 study revealed several uncertainties with respect to shield weight estimates, an accurate knowledge of which is important. Conference Report No. 383-36 (9-17-65) summarizes the opinions of the meeting.

REFERENCES

1. Phillips, W., "O-Ring-Alkali Metal Compatibility," JPL SPS 37-33, Vol. IV, pp. 132-133, June 30, 1965.

2. Phillips, W., "0-Ring-Alkali Metal Compatibility," JPL SPS 37-34, Vol. IV, p. 170, August 31, 1965.

3. Davis, J. P., Gronroos, H., and Phillips, W., Review of Proposed In-Pile Thermionic Space Reactors, Part I - General, (unclassified) to be published as JPL TM.

4. Gronroos, H., Review of Proposed In-Pile Thermionic Space Reactors, Part II - Reactor Physics, (Confidential RD) to be published as JPL TM.

5. Phillips, W., Review of Proposed In-Pile Thermionic Space Reactors, Part III - Nuclear Fuels, (Secret RD) to be published as JPL TM.

6. Gronroos, H., and Kikin, G., "Analog Study of Thermionic Reactor Stability," JPL SPS 37-35, Vol. IV, pp. 180-190, October 31, 1965.

MHD CONVERSION SYSTEMS

NASA Work Unit 120-27-06-03-55
JPL 320-70301-1-3830

David G. Elliott

OBJECTIVE

The objective of the liquid-metal magnetohydrodynamic **(MHD)** investigation is to determine the conceptual feasibility of a nuclear-electric powerplant with no moving mechanical parts that could be developed at an early date for nuclear-electric propulsion. The liquid MHD system operates without moving parts by accelerating 2000°F liquid lithium with cesium vapor and decelerating the lithium to produce electric power in a magnetohydrodynamic generator.

Figure 1 shows the program being followed with approximate target dates. The four main tasks are: (1) small-scale (5 kw) generator experiments to investigate the basic operating principles of ac magnetohydrodynamic generators, (2) cold tests of a conversion system with a 50-kw generator using liquid sodium-potassium alloy (NaK) in place of lithium and nitrogen gas in place of cesium vapor, (3) evaluation of materials and reduced-scale components at 2000°F in capsule and loop tests, and (4) design of a 2000°F 300-kwe cesium-lithium conversion system for testing with electric heating.

Results obtained during the last six months were reported in Ref. 1 - 4.

AC GENERATOR

Progress

Figure 2 is a photograph of the 5-kw ac generator prior to winding the stators, and Fig. 3 shows the flow channel with the upper stator block removed. The wound stator blocks are shown in Fig. 4. In the assembled generator the stator blocks are clamped to copper side strips to form the flow channel and then clamped between a nylon inlet nozzle and nylon exit block.

The magnetic field profile was found satisfactory in dc measurements, but an error in stator heat treatment reduced the attainable field. The empty-channel ac operation was also found to be satisfactory except for effects of the improper heat treatment, and the instrumentation and control equipment were satisfactorily checked out. It was not found possible, however, to proceed to the NaK tests due to cumulative distortion of the slot plugs, copper strips, and nylon blocks by thermal expansion during the ac tests.

Plans

The existing parts are being repaired and reassembled for NaK testing, and a second pair of stators is in fabrication. Material has been ordered for a third and fourth assembly.

NaK-NITROGEN CONVERSION SYSTEM

Progress

Design of the separator, generator housing, dummy generator (for flow tests), and diffuser has been completed. A magnetic mockup of the 50-kw ac generator for the system was tested with dc excitation, and the desired field profile and variation of wave speed with distance to match the fluid deceleration was obtained.

A critical review of known ac magnetohydrodynamic generator concepts was conducted in consultation with Prof. William D. Jackson of MIT during a five-week visit by him in August and September. Prof. Jackson had previously visited MHD laboratories in Germany and Russia, and these visits, together with previous contacts by him with laboratories in Great Britain, and discussions between JPL and U.S. laboratories active in liquid-metal generators and pumps (General Electric, Atomics International, Lewis Research Center, and MIT) gave confidence that all pertinent work was known and the literature file complete. The review confirms that the design approach being followed is the best possible in the light of present information.

Analysis of the 50-kw generator is continuing. An unexpected performance gain was found in studying the optimization of the slot shape. It was found that tapered, cusp-shaped slots, as illustrated in Fig. 5, permit a very deep slot before the iron saturates. The resulting reduction in current density, to which winding loss is proportional, is illustrated by the curves in Fig. 5. For the 50-kw generator a two-fold reduction in current density is obtained with the tapered slots.

Plans

The separator, generator housing, diffuser, and dummy generator will be fabricated and tested with nitrogen and water to verify calculated hydraulic performance. The generator design will be completed and fabrication started, aiming at system operation in December 1966.

MATERIALS EVALUATION

Progress

In a 2000°F cesium-lithium system, materials harder than columbium may be needed for the parts of the separator where the lithium initially impinges. Two materials of interest for this purpose, TiC and ZrC, were screened for lithium compatibility in static capsule tests. After exposure to 2000°F lithium for 1700 hr, the TiC sample was unchanged, except for a slight increase in surface porosity visible at 800 x magnification. The ZrC sample had developed a number of cracks (judged due to thermal shock rather than chemical attack) and showed a slightly greater increase in porosity than the TiC sample.

Two 2000°F cesium-lithium loops are being assembled for evaluating the effect of lithium velocities up to 700 ft/sec. The first loop (Fig. 6), circulating lithium only, is ready for performance testing of the helical induction lithium pump at 2000°F and for obtaining preliminary data on lithium erosion of candidate separator and containment materials at velocities up to 250 ft/sec. Fabrication of the major Cb-1% Zr lines for the second loop, which employs two-phase cesium-lithium flow to achieve higher velocities, has been completed.

As an extension of the erosion research, monitoring is being provided for NASA contracts with Westinghouse (Contract AS 7-390) and Rocketdyne (Contract AS 7-391) on turbine blade erosion. In addition to discussions with these organizations, L. Hays visited four laboratories in Great Britain in October to exchange information on erosion research. A report on this visit will be published as Ref. 5.

Plans

Static capsule tests of electrical insulators in 2000°F lithium will continue, the lithium-erosion loop will be operated, and fabrication of the cesium-lithium loop will continue.

CESIUM-LITHIUM CONVERSION SYSTEM

Progress

A nominal 300-kwe, 2000°F cesium-lithium conversion system is being designed, and methods of testing this system are being studied. The first step was a final review of the possible liquid MHD cycles and working fluid combinations using a cycle analysis program which calculated cycle efficiency, radiator area, and comparative system weight over the range of temperatures of interest. The weights are shown in Fig. 7, confirming that the cesium-lithium separator cycle is the correct one to pursue. Details of the cycles and assumptions were presented in Ref. 1 and 3.

Development of a 150-v heater for lithium at temperatures to 2000°F at high power levels (5 Mw) has continued. The purpose is to develop a heater design for the 2000°F prototype system and also provide a heater for immediate use in the 100 kw(th) cesium-lithium erosion loop. Conduction heaters with Cb-1%Zr sheaths, beryllia insulation, and tantalum center conductors were tested in a vacuum chamber. Ten cycles from ambient to 2000°F were conducted, in addition to 50 hr of steady-state tests at 2000-2100°F and the application of 200-v across the insulation, with no deleterious effects on the beryllia.

Plans

Design studies of the cesium-lithium conversion system will continue with emphasis on assuring that the NaK-nitrogen conversion system and the cesium-lithium loop are oriented as closely as possible toward solution of the problems of the cesium-lithium system. A JPL report on the cycle calculations will be published.

TWO-PHASE TUNNEL

Progress

The basic shock studies with the supersonic two-phase tunnel were completed and a summary of results will be presented in Ref. 6.

Plans

Tunnel experiments with a dissolving gas in support of the cesium-lithium system design will be conducted at a later date.

REFERENCES

1. Elliott, D., Cerini, D., Hays, L., Weinberg, E., and O'Connor, D., "Liquid MHD Power Conversion," JPL SPS 37-34, Vol. IV, pp. 163-170, August 31, 1965.

2. Elliott, D., Cerini, D., Hays, L., and Weinberg, E., "Liquid MHD Power Conversion," JPL SPS 37-35, Vol. IV, pp. 165-170, October 30, 1965.

3. Elliott, D., Cerini, D., Hays, L., and Weinberg, E., "Liquid MHD Power Conversion," JPL SPS 37-36, Vol, IV, December 31, 1965.

4. Elliott, D. G., "Liquid-Metal MHD Power Conversion for Space," Northeast Electronics Research and Engineering Meeting, Boston, Massachusetts, November 4-5, 1965, NEREM Record pp. 140-141.

5. Hays, L., Turbine Erosion Research in Great Britain, JPL TM 33-271 (to be published).

6. Eddington, R. B., "Investigation of Shock Phenomena in a Supersonic Two-Phase Tunnel," AIAA Third Aerospace Sciences Meeting, New York, January 24-26, 1966, Paper No. 66-87.

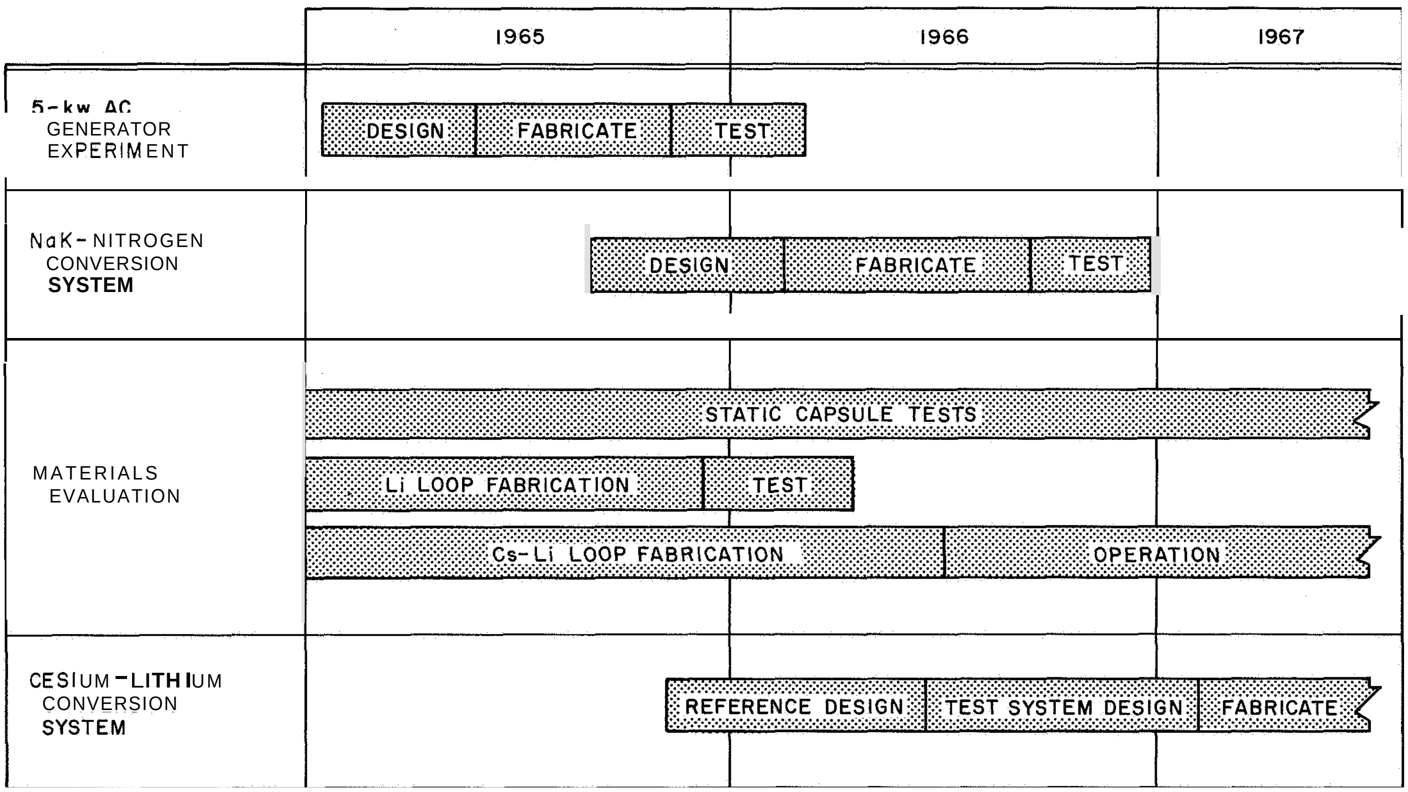

Fig. 1. MHD program schedule

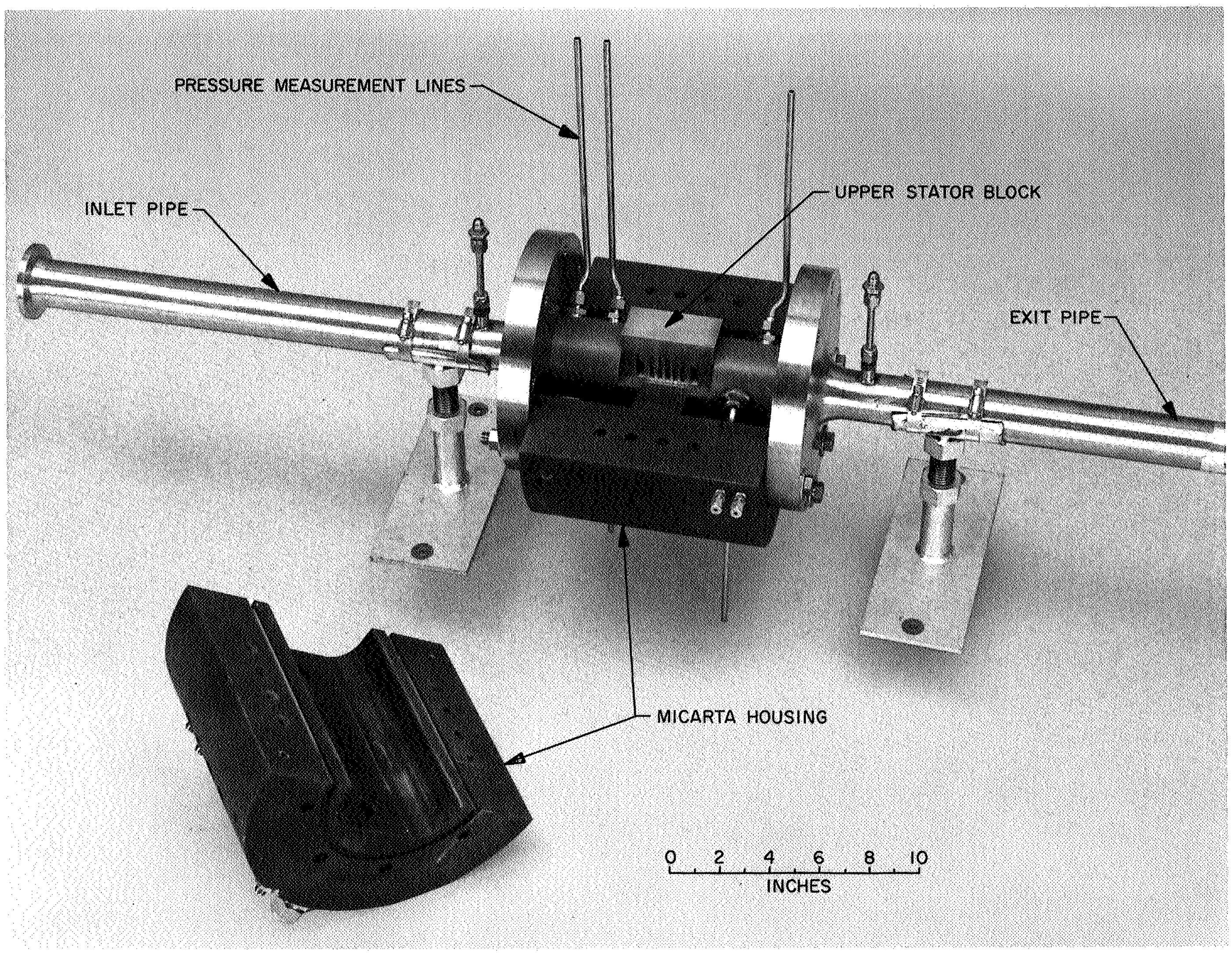

Fig. 2. Experimental 5-kw ac MHD generator

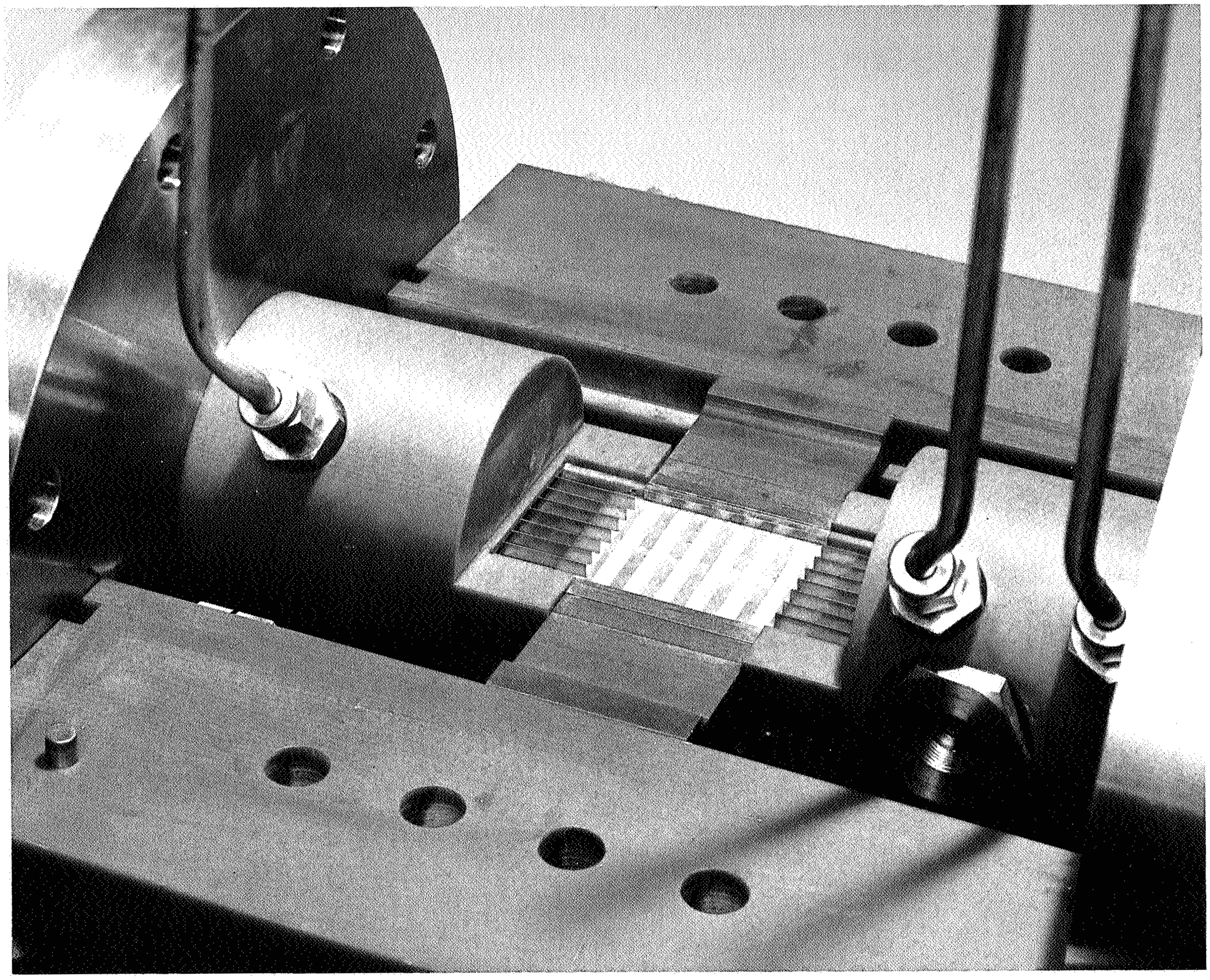

Fig. 3. **AC** generator flow channel with upper stator block removed

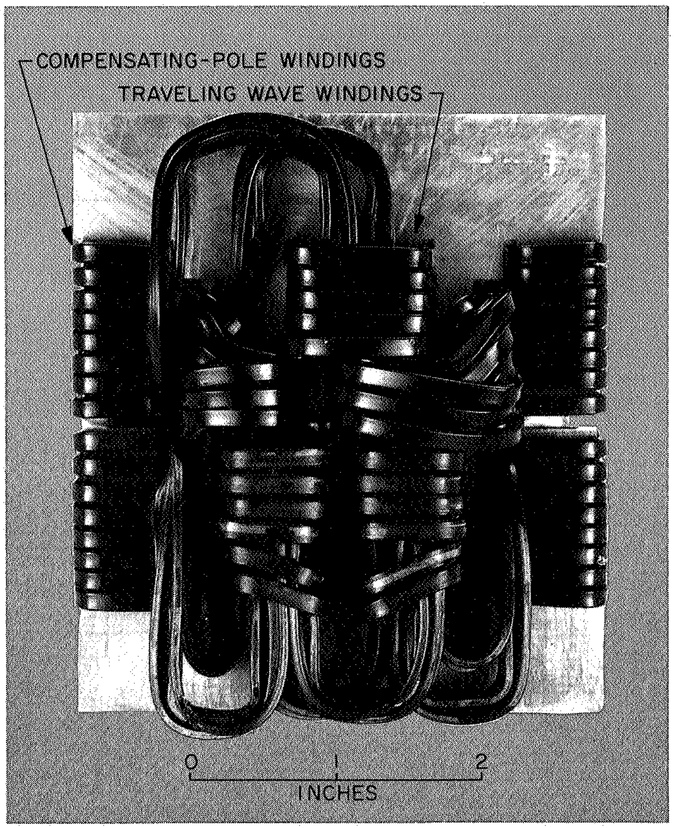

Fig. 4. AC generator stators

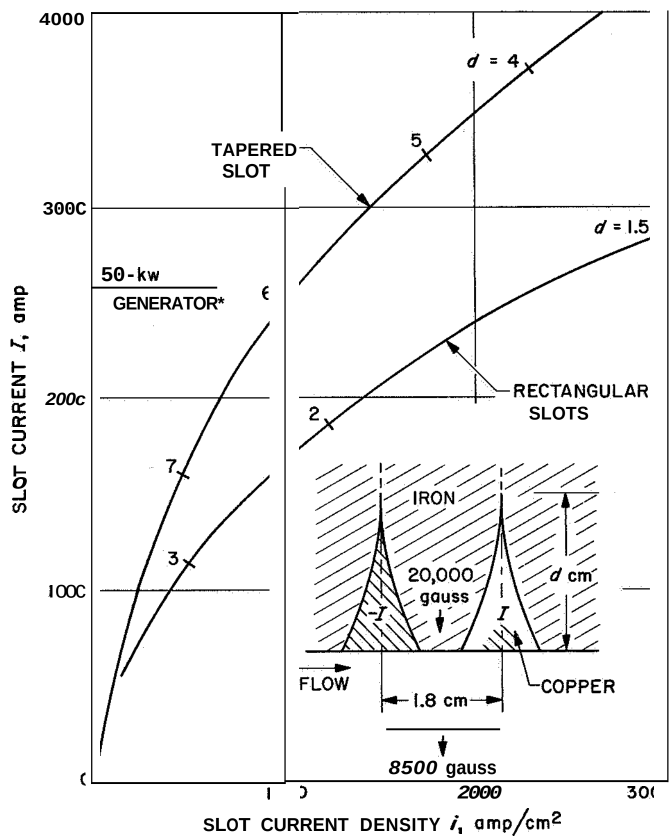

Fig. 5. Variation of slot current with current density for tapered and for rectangular slots

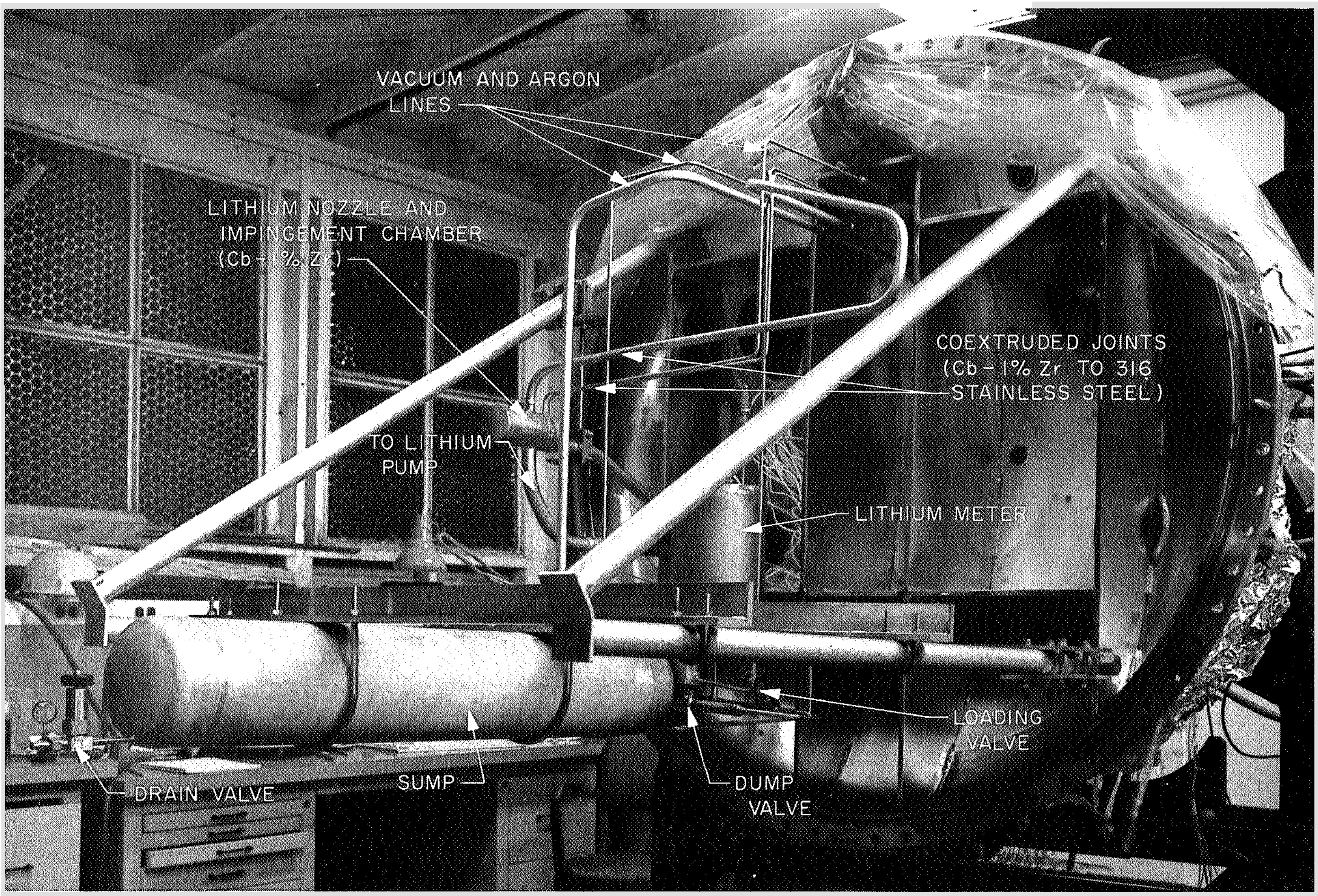

Fig. 6. Lithium erosion loop

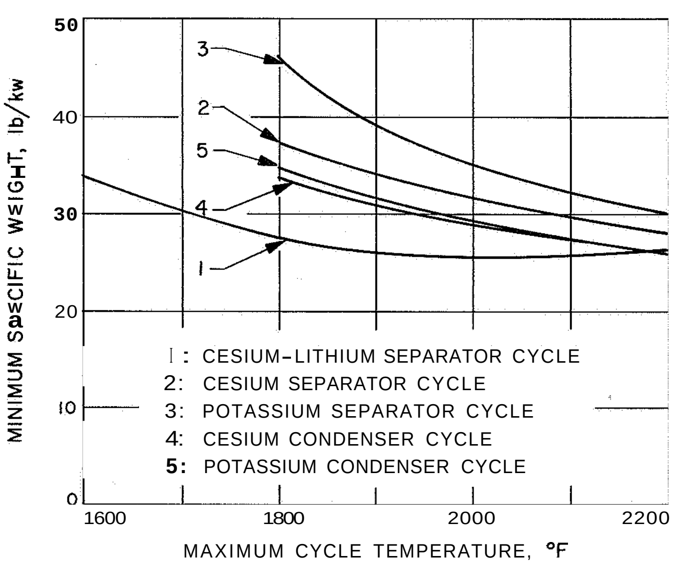

Fig. 7. Comparison of specific weights of liquid MHD systems

SPACE POWER (123)

SOLAR POWER GENERATION (123-33)

PHOTOVOLTAIC ENERGY CONVERSION
NASA Work Unit 123-33-01-01-55
JPL 323-30101-2-3420
D. Ritchie

OBJECTIVE

The objectives of this program are to explore a concept for deploying lightweight large area solar arrays, to develop the necessary design knowledge in order to ultimately fabricate prototype units, and to continue a program on standardization and testing of solar cells and materials.

INTRODUCTION

Activities during the first half of FY 1966 in support of photovoltaic energy conversion have included balloon flight solar cell calibrations, relocation of facilities, and thin cell assembly investigations. In addition, The Ryan Company, San Diego, California, has been under contract to JPL for the development of a large-area, deployable, lightweight solar array structure.

LARGE-AREA LIGHTWEIGHT ARRAY

The Ryan Company, San Diego, California, has been performing on JPL contract 951107 for the development of a large-area, lightweight rollup solar array since May 1965 (Fig. 1). The contracted effort is a three-phase program: concept development, design, and fabrication of a prototype element. The phase I effort was completed in August 1965 and reported in Ryan Report No. 20869-1.

During the phase I investigations of the beam sections, it appeared that the differential movement of the beam caps created by wrapping would have to be accommodated in a slip joint. Although the first design and test sample did fold, it had very little torsional rigidity. To increase the torsional rigidity and load-carrying ability, the slip joint beam design was eliminated, and designs were produced to resist the horizontal shear created by folding. Test beam samples constructed to two of these cross-sectional designs (Fig. 2) proved that they would roll and extend while taking more than the required load and exhibiting high torsional rigidity. Both beam types will utilize thin, high-strength materials. The major advantage of Design B (Fig. 2), at this time, is an increased torsional stiffness and a seemingly more efficient section, since this configuration is more resistant to buckling.

Many sample sections were constructed to test various beam characteristics. Material selection for the metal beam assemblies was based upon stock available. Representative samples of these 2-ft-long beam assemblies were folded and returned to shape to take the following loads:

Matl. 0.0060 AM 355 CRT - 268 in.-lb

Matl. 0.0045 AM 355 CRT - 476 in.-lb

Matl. 0.0045 AM 355 CRT - 420 in.-lb

Moment capability was altered by changing both the cross-section height and the material thickness. The maximum moment capability required is 274 in.-lb. Titanium strips have been chem-milled to thicknesses calculated to give the required strength and folding qualities.

As a result of the phase I investigations, titanium has been selected as the metal best suited to this design because of its high strength-to-weight ratio, nonmagnetic properties, low creep characteristics, and noncorrosive properties.

The investigations also indicated that the circular closed-section beam design has sufficient advantages to warrant the selection of this configuration for further development. The approximate dimensions for the beam are: 3.5 in. wide by 1.75 in. high when deployed and approximately 4 in. wide when folded. The material is 0.006-in. titanium. Specimens of the beam section have been fabricated and tested. Results show the section capable of folding for stowage and capable of extending to resist the required moment.

The phase II design effort is approximately 50% complete at this time. The phase II effort is scheduled for completion by mid-January. Phase III, the prototype fabrication, is estimated to be complete by June 1966.

BALLOON FLIGHT PROGRAM

A series of four balloon flights was successfully conducted in July and August 1965 for the calibration of solar cells. The series of flights included stability and correlation tests of previous balloon standard solar cells, a solar cell filter experiment, wide range spectral response solar cell calibrations, correlation and calibration of solar cells for Wright-Patterson AFAPL, and evaluation of a method to determine the effects of sky radiation on balloon-calibrated solar cells. Flight data are presently being processed. Reports of the 1965 balloon flight series will be available by April 1966. An oral presentation of the sky radiation measurements was presented at the 1965 Photovoltaics Specialist Conference at Goddard Space Flight Center on October 20, 1965. This paper will be published as a JPL TR.

CELL INVESTIGATIONS

Solar cell investigations are continuing with emphasis on silicon solar cells in the 8-mil-thickness region. Assembling techniques are being evaluated in order to minimize cell module weights. Both conventional contact and wraparound contact cells are included in these investigations. Cell matrices of 0.25 lb/ft^2 have been fabricated and are scheduled for testing (Fig. 3). A universal bus-bar has been developed which can be used for either conventional or wraparound contact type cells (Fig. 4) 1 x 2 and 2 x 2 cm in size. Patents have been applied for regarding this cell interconnection technique.

FACILITIES

The photovoltaic development efforts at JPL have recently established centralized facilities in the Guidance and Control Laboratories (Bldg. 198) at JPL. A total of 1800 ft^2 is utilized with the following capabilities:

Cell electrical measurements (Tungsten and Xenon)

Thermal cycling

Panel assembly (prototype)

Resistance measurements

Mechanical strength measurements

Vacuum thermal equilibrium measurements*

Materials investigation (adhesives and bus-bars)

Intensity and temperature measurements (Tungsten-Xenon, -30 to 140 mw/cm^2, -20 to 70°C)

Tunnel oven soldering

UV test facility

*In procurement process – expected completion by May 1966.

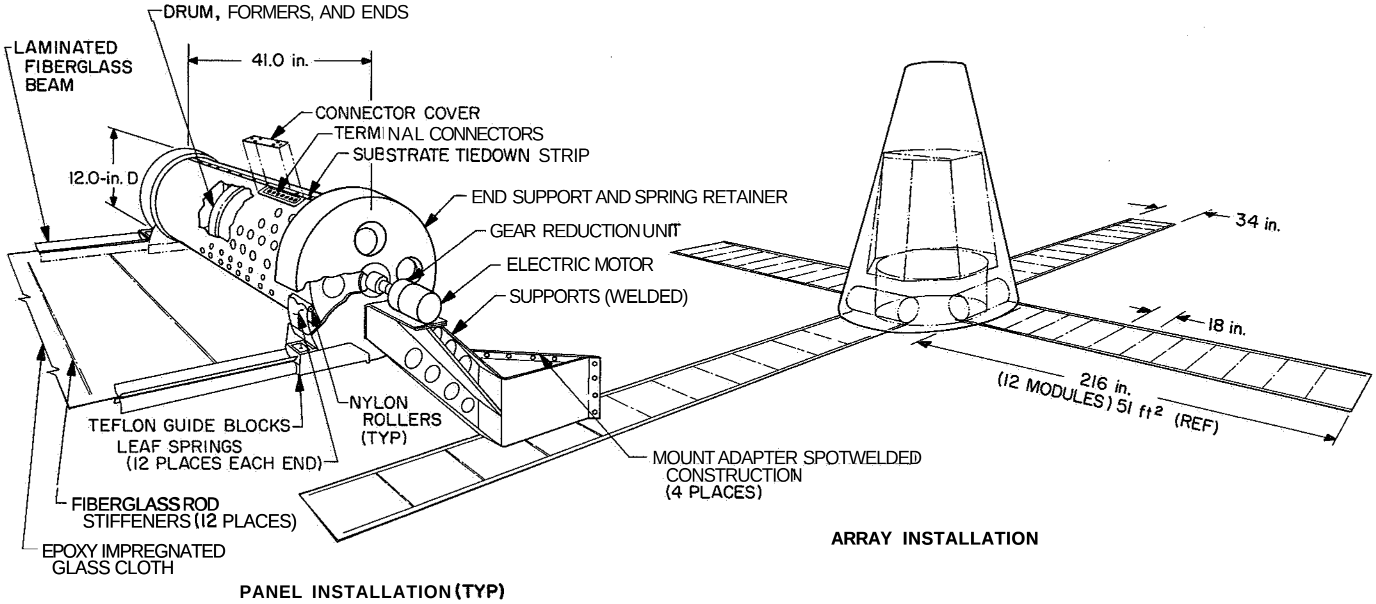

Fig. 1. Deployable solar array structure

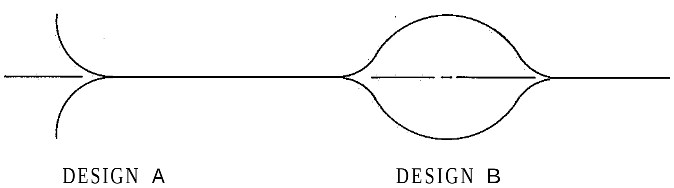

Fig. 2. Beam cross section

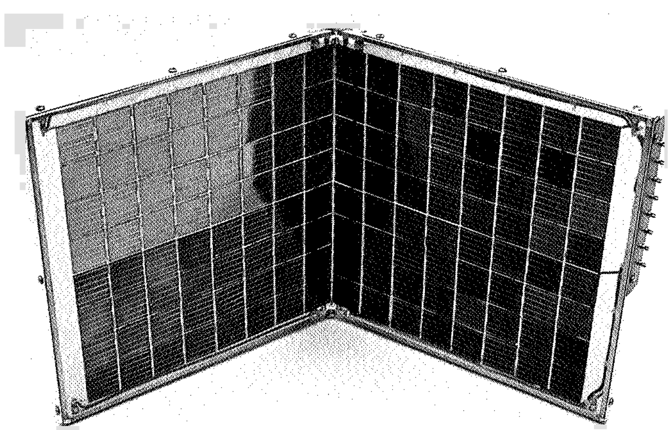

Fig. 3. Solar panel assembly (0.25 lb/ft^2)

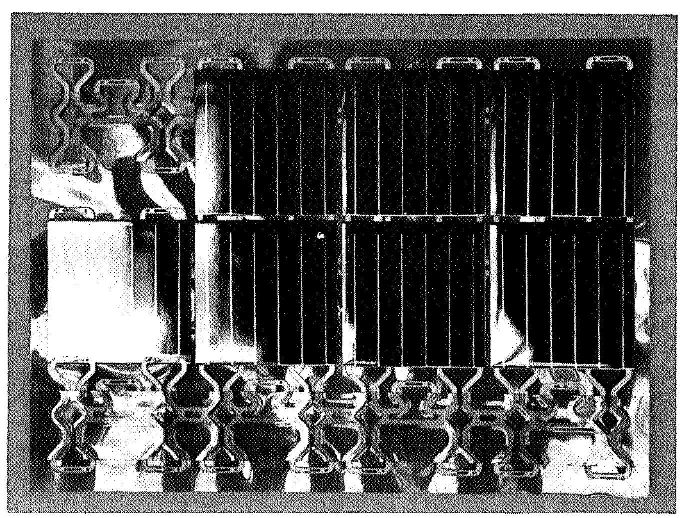

Fig. 4. Universal bus bar (front)

HIGH POWER PHOTOVOLTAIC SYSTEMS

NASA Work Unit 123-33-01-02-55
JPL 323-30801-2-3430

D. Ritchie

OBJECTIVE

The objectives of this program are the development of the technology for the design and fabrication of high-power solar array systems and the demonstration of the feasibility of a 20-w/lb solar array.

INTRODUCTION

In support of high-power photovoltaic systems, efforts to date have centered around a 20 w/lb feasibility program in the 10- to 50-kw power region. In February 1965, a contract was initiated with the Boeing Company, Seattle, Washington, for the development of preliminary designs for 10- and 50-kw arrays with power densities estimated at 20 w/lb, performance of tradeoff studies, and an analysis of manufacturing and facilities requirements.

ACTIVITIES

Since the last semi annual report (JPL TM 33-243), Boeing has completed preliminary design of two large arrays, based on the folding modular concept, for the Saturn IB/Centaur and Atlas/Centaur launch vehicles. The array designed for installation on a spacecraft launched by a Saturn IB/Centaur provides 42. 1 kw of raw power at a Sun probe distance of 1 astronomical unit (AU). This is achieved through the deployment of 4433 ft^2 of active solar cell area, at approximately 9. 5 w/ft^2 efficiency. A gross deployed area of 4944 ft^2 is necessary and includes nonactive structural and mechanical area. The total array weight has been calculated to be 1925 lb for a power conversion-to-weight ratio of approximately 21 w/lb. The Atlas/Centaur array preliminary design provides 9.5 kw of raw power with a gross deployed area of 1004 ft^2. The total array weight has been calculated to be 510 lb, yielding a power density of 18. 5 w/lb.

The two solar array designs were studies to determine the manufacturing methods and techniques that would be required for fabrication. The construction of both the Atlas/Centaur and the Saturn IB/Centaur arrays are similar to the extent that manufacturing methods would be the same for both arrays and, therefore, were not considered separately. The successful fabrication of the solar arrays that have been designed will depend largely upon the ability of manufacturing shops to maintain close control of fabrication tolerances affecting the gross weight of the completed arrays. Manufacturing methods and techniques must be developed so that consistent and reliable results are obtained. The process materials that are used throughout the array (adhesives, silicone rubber, solder, paint, etc.) have stringent requirements concerning thickness and quantity of application that will be limiting factors in the fabrication. There are many assembly problems due to the size and fragile nature of the array that will have to be resolved on the tool designer's drawing board as the fabrication and assembly procedures evolve. The studies thus far indicate there are no insurmountable problems that would affect fabrication feasibility.

As a portion of this contract, program plans have been developed for a full scale prototype solar cell array of the 20 w/lb class to be adaptable for either the Atlas/Centaur or Saturn IB/Centaur configurations, based on the present state of the art. The program plans have also included analysis of size and type of manufacturing facilities required to support full scale panel fabrication.

There are four bimonthly reports, designated the "20 Watt/Pound Solar Array Feasibility Study," which have been released by Boeing and are available through JPL. The bimonthly reports contain in detail the analysis, tradeoffs, assumptions, and supporting data used by Boeing to support this program.

This contract is scheduled for completion during mid-December, with the delivery of three sample 1-ft^2 solar cell assemblies and two 1/20-scale models of each solar array to demonstrate deployment. A final review of the Boeing contract is scheduled for January 19 at JPL.

FUTURE WORK

Future activities in support of the 20-w/lb solar array are anticipated as a result of the Boeing study. Presently, attention is being directed toward the fabrication of one quadrant of the Saturn IB/Centaur solar array. Estimates of such an effort include a program of 2 to 3 years at a cost of 3 to 5 million dollars. The program would include development, design, fabrication, and testing of the array. Program plans are being generated at JPL to identify major milestones to accomplish this effort.

THERMIONICS DEVELOPMENT
NASA Work Unit 123-33-02-01-55
JPL 323-30201-2-3420
P. Rouklove

OBJECTIVE

The objectives of this program are to modify the mechanical configuration of thermionic diodes to reduce heat losses and increase the efficiency of the diodes, to fabricate and test a thermionic generator potentially capable of producing 200 w of output power, to develop a high-power converter design, and to investigate techniques to improve thermionic diode output voltage.

INTRODUCTION

The development of solar heated thermionic converters and generators was continued under NASA sponsorship. The effort was initiated in FY 1962 and extended as consequence of the high rate of progress. The extent of that progress and general outline of the effort were presented in the last SR/AD progress report (JPL TM 33-243); the present report presents only the progress of the last 6 months.

THERMIONIC CONVERTER DEVELOPMENT

Under contract 951225, issued in March 1965, the effort of Electro-Optical Systems (EOS) was divided into two major tasks: (1) verification of the performance of different electrode materials (and combinations of the same) at different operating parameters, and the analytical study of various converter geometries and (2) incorporation of these results in the fabrication and tests of six engineering models of thermionic converters.

The electrode material evaluation is to be performed in a test vehicle especially developed for that effort. A vehicle with easily interchangeable electrodes and variable spacing mechanisms of high accuracy has been designed, its subassemblies tested, and the vehicle assembled. The study of the first emitter-collector materials, rhenium - rhenium, has been initiated and will be followed by studies of tantalum - tantalum, rhenium - nickel, rhenium - molybdenum, etc. The analytical and component studies of the converters have been pursued. The contractor has performed calculations, backed by experimental data, on collector heat transfer and radiator heat rejection (including long term testing to ascertain the stability of "Rokhide" coatings). The techniques of prefabricated and pretested metal-to-ceramic seals have been successfully achieved, including cycling tests. The electron-beam welding of rhenium to rhenium has been developed and "pull tests" were made to ascertain the soundness of the weldments. Details of the construction of the first engineering model of the improved thermionic converter have been presented to JPL and thoroughly reviewed. The final goal of the program is the development of a reliable converter capable of an output power density of 20 w/cm^2 of emitter area at an output voltage of 0.8 v and an emitter temperature of 2000°K.

Under contract 950671 with Thermo-Electron Engineering Company (TEECO), the repair of the four converter generator which was damaged previously during laboratory tests was continued. It is expected that the generator will be delivered in early January for tests at JPL.

A fixed-price contract (No. 951230) was initiated in May 1965 with TEECO for the design of a six-converter solar thermionic generator capable of delivering 200 to 250 ew at better than 10% conversion efficiency. This design was submitted to JPL for approval. The design and the calculations leading to it have been approved and the effort is in the final reporting stage.

Contract 951263 has been negotiated with TEECO for the development of an improved high-temperature thermionic converter and the design of a multiconverter generator. The converter improvements are to include a new convoluted emitter sleeve structure, made of thin rhenium tubing (as compared to the pressure-bonded tantalum-rhenium structure previously used) and an improvement of the collector heat transfer characteristic. The design of the multiconverter generator is to be composed of 12 to 18 converters which will be developed under Task I of this contract. This generator is to be capable of delivering 800-to 1000-w output power in cislunar space from the thermal energy supplied by a 9.5-ft-diameter mirror. This task is to result in the working drawings for this generator which are to be supplied with all supporting calculations.

In order to evaluate the compatibility of "additives" with the materials used in the present state of the art of thermionic converters, hardware negotiations have been initiated to provide fixed-price engineering models of existing converters with cesium fluoride reservoirs. These converters will be operated for long periods in life-test equipment available at JPL and will provide data on compatibility of cesium fluoride with metals and materials used in thermionic converters.

In order to evaluate the use of a "heat pipe" as a means of removing collector heat, an effort has been initiated to obtain fixed-price converters incorporating a heat pipe attached to the collector barrel. These converters will be performance-tested at JPL and the effect of the heat pipe evaluated.

IN-HOUSE EFFORTS

Parametric Tests of Individual Converters

The 20 converters, purchased under fixed-price contract P. O. No. AES-310910 from Thermo Electron Engineering Co. , are being parametrically tested and evaluated. The results of the tests to date indicate that a fair amount of reproducibility in the converter manufacturing techniques has been achieved. The measured converter output characteristics of the 10 diodes tested varied only ±5% from the average. Two papers covering the test results of five thermionic generators and the parametric test of 80 converters, performed at JPL, have been presented at the International Thermionic Power Conversion Symposium in London.

LIFE TESTS

Performance evaluation of high temperature thermionic converters over extended periods of time is being performed in-house by JPL. Figure 1 is a summary of life test data obtained, to date. Almost 48, 000 hr of converter operating time have been accumulated on 12 converters, with converter TEP- 1 operational for almost 11,000 hr. During life-tests, converter power outputs have remained nearly constant unless a failure occurred. Four failures have occurred to date; in all cases a buildup of deposited material on the collector has resulted in a diode internal short.

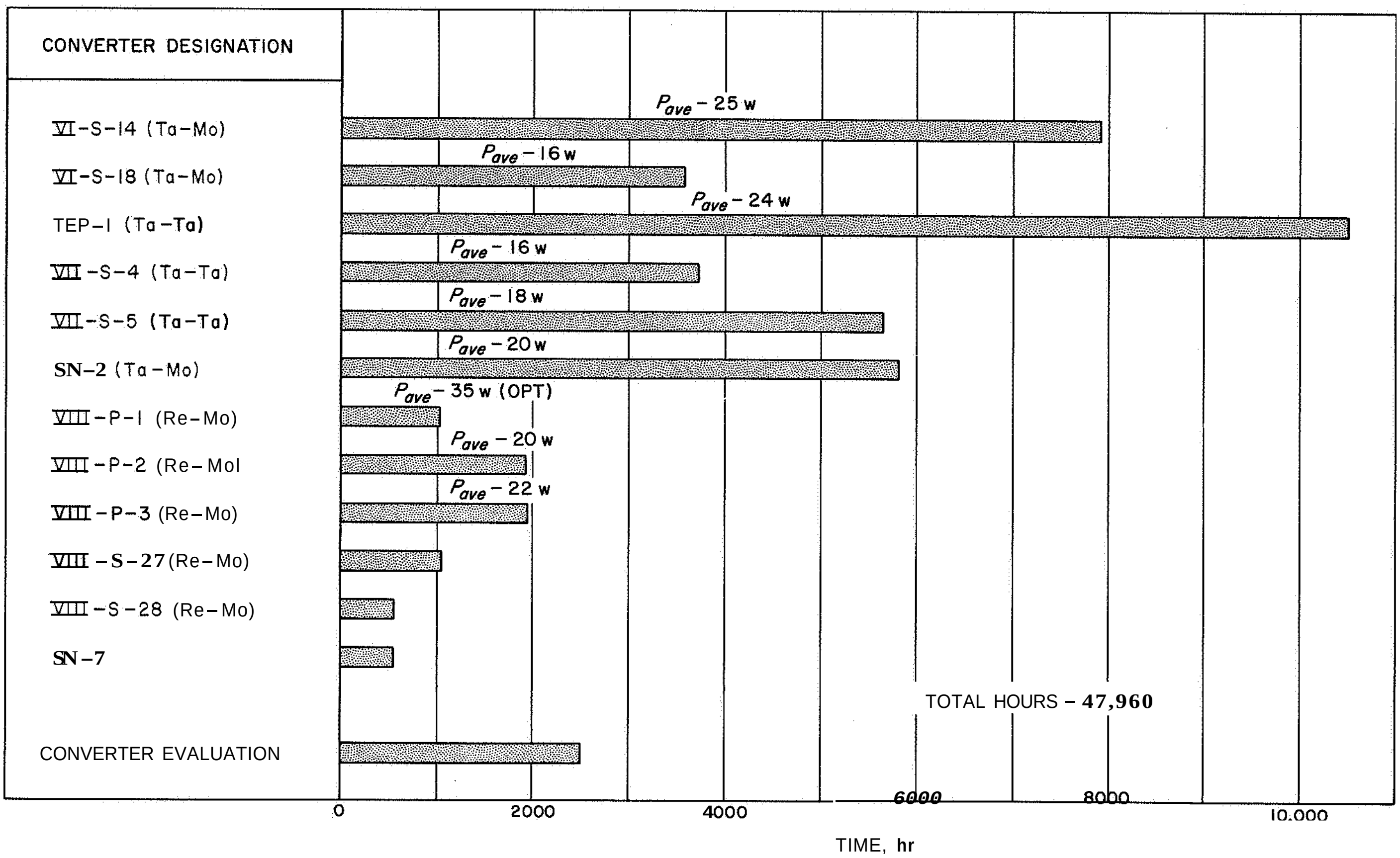

Fig. 1. Life test summary

THERMIONIC SUPPORTING RESEARCH
NASA Work Unit 123-33-02-02-55
JPL 323-30601-2-3420
S. Luebbers

OBJECTIVE

The objective of this program is to study the performance of thermionic converters in the presence of cesium fluoride and inert gas additives. During the evaluation of these additives, an analytical model will be developed to describe the effect of each additive.

INTRODUCTION

The supporting research program described herein is a continuation of effort initiated by JPL in 1964 under NASA sponsorship. The program objectives have remained unchanged and are repeated for convenience:

1. Obtain reliable thermionic converter operation design data.

2. Better understanding of the conversion process so the interaction of various parameters may be predicted in advance of converter or generator design.

3. Developing new techniques to improve converter electrical performance and reliability.

This effort is being performed by Thermo Electron Engineering Corporation under Contract 951262. The contract period extends one year, June 1965 to June 1966 and is funded at $200,600.

DESIGN DATA

Since the last reporting period, the first year of supporting research has been concluded. From this program, a complete set of parametric data for rhenium-molybdenum electrode systems has evolved. Included are performance maps which allow the thermionic converter designer to accurately predict performance for these particular electrodes. The parametric data provides operational information for variations in emitter temperature, cesium reservoir temperature, collector temperature, and spacing. The first objective has thus been achieved for rhenium-molybdenum converters.

CONVERSION PROCESS

The analytic model previously described has been refined to include a wider range of parameter values. The model mathematically describes thermionic converter operation from slightly above the preignition point, well into the saturated region. Since this includes the maximum power point, this region is felt to be of great importance. This understanding has brought partial fulfillment of the second objective.

NEW TECHNIQUES

The current supporting research program places emphasis upon the third objective; that is, to develop new techniques to improve converter electrical performance and reliability. Two approaches are being taken to reach this objective. The first approach utilizes cesium-fluoride as a surface additive agent; the second approach utilizes argon as a plasma additive agent. Each of these approaches offers the possibility of significantly improving the electrical performance. The introduction of an additive agent necessitates modifying the analytical model to include the additive affects.

SURFACE ADDITIVE

Cesium-fluoride evaluation is being performed in a previously described tungsten-molybdenum test vehicle. Initial results have appeared successful. Figure 1 illustrates the performance enhancement realized by including cesium-fluoride. At 0.7 v, the power output is seen to increase more than 400%. A problem of major concern is the obtainment of reproducible data. The cesium-fluoride affects appear to be time-dependent, with performance decreasing with time. The reason for this time-dependence has not been ascertained.

PLASMA ADDITIVE

Argon has been selected as the plasma additive agent. Examination of available data indicates argon is nearly transparent to the converter electron current while representing the largest collision cross-section to migrating ions. Plasma additive affects will be evaluated with both tungsten-molybdenum and rhenium-molybdenum test vehicles.

The first quarter of this program has been utilized in the modification of the test vehicles to permit greater accuracy in emitter temperature measurement and the introduction of plasma additives. After completion of the test vehicle modifications, the electrode work functions were carefully documented. The plasma additive will be added to the test vehicle in the very near future.

FUTURE WORK

Plans for the next reporting period include:

1. Determination of the mechanism by which cesium-fluoride effects are time dependent and investigate this dependence if possible.

2. Expansion of the analytical model to include the effects of cesium-fluoride.

3. Obtain parametric data for both surface and plasma additives.

4. Experimental investigation of plasma additives other than argon.

5. Expansion of the analytical model to include the effects of plasma additives.

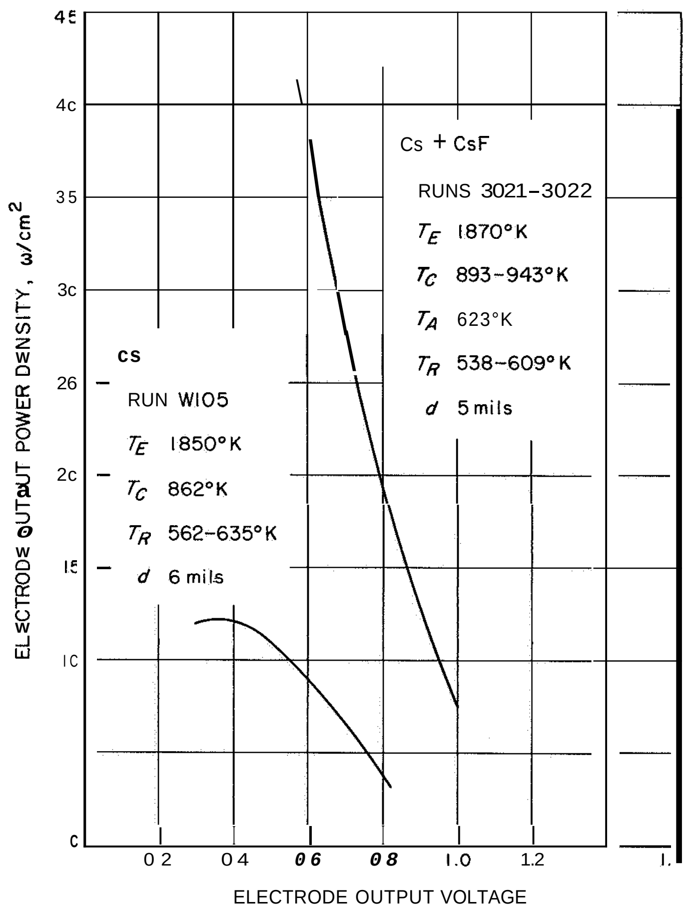

Fig. 1. Performance enhancement with cesium fluoride

SOLAR TEST FACILITIES

NASA Work Unit 123-33-02-03-55
JPL 323-30701-2-3420
R. Boring

OBJECTIVE

The objectives of this program include the sunlight performance testing of solar thermionic generators and photovoltaic arrays and the calibration and testing of individual solar cells and solar cell modules.

INTRODUCTION

This section describes the activities at the JPL Solar Test Facility at Table Mountain, California,

ACTIVITIES

During the second and third quarter of 1965, effort was directed toward completing the contract negotiations with the new JPL Solar Test Facility contractor (Lockheed) and his familiarization with the facility capabilities and requirements. Familiarization tasks included installation of solar concentrator (S/N1) in the solar tracker, alignment of the tracker, and performance of modified Hartmann tests. The facility was then moved to its new location to the east of the astronomical observatory. In preparation for solar testing of a three-converter generator from EOS and a four-converter generator from TEECO, the S/N1 mirror was reinstalled, aligned, and spot-checked to ensure repeatability of data. The mirror was then calibrated using a water-flow calorimeter and solar flux control to permit meaningful testing of the above-mentioned generators.

Presently, a three-converter generator is undergoing extensive solar testing. These tests should be concluded prior to January 1966 if weather permits. Immediately following this evaluation, a four-converter generator (JG-3) is expected to be ready for solar tests.

During November 1965, the installation and checkout of the JPL-designed and fabricated improved solar tracking system will be completed. Should installation and checkout of the improved tracker proceed as scheduled, the JG-3 generator will be tested with it; otherwise, the present tracker will be used.

FUTURE WORK

After the two generators have been fully evaluated, test activities planned for the future include solar evaluation of solar concentrator S/N3, (which is a new 9. 5-ft-diameter mirror to be delivered to JPL during the first quarter of 1966) and the evaluation of the first single-skin 11.5-ft-diameter solar concentrating mirror. This mirror, which is to be delivered during the second quarter of 1966, will be the first to be tested in the new tracker.

SOLAR POWER SYSTEM DEFINITION
NASA Work Unit 123-33-05-01-55
JPL 323-30901-2-3420
K. Dawson

OBJECTIVE

The objectives of this program are to define the problems associated with mechanizing sophisticated spacecraft electrical power systems, and to develop the techniques required to solve these problems. This effort stresses optimization of power system mechanizations, providing reliable overall system operation by using redundancy, failure detection and fault clearing, and development of optimum in-flight monitoring techniques.

SOLAR THERMIONIC-SOLAR PHOTOVOLTAIC COMPARISON

This study investigates analytically the tradeoffs between solar thermionic and solar photovoltaic power systems in the 100- to 4000-w range. Weight, area, and reliability are the parameters of prime importance. The comparison investigates systems for the following four applications:

1. Solar and planetary probes over a Sun-probe range of 0.3 to 1.7 astronomical units (AU).
2. Earth orbiters for circular, equatorial orbits at altitudes of 500, 3,000, and 10,000 km.
3. Lunar, Mars, and Venus orbiters for eccentric orbits of 10- to 50-hr periods.
4. Lunar stations for daytime operation only.

After a competitive procurement, Electro Optical Systems, Pasadena, California, was awarded a $58,401 fixed-price contract to perform the work. JPL worked closely with the contractor in establishing estimates of the present device capabilities and future device potentials to be used by the contractor carrying out the comparison. The contractor progressed in a satisfactory manner throughout the program, and a rough draft of the final report has been received and reviewed by JPL. The final report is expected to be out in finished form by January 15, 1966.

SOLAR THERMIONIC POWER SYSTEM DESIGN

A solar thermionic power system design effort is a logical followon of past studies in the areas of solar thermionics. This effort is intended to design solar thermionic power systems for each of two specific missions:

1. An Earth-orbiting system (200-nm perigee to 25,000-nm apogee) that is capable of delivering a minimum of 1000 ew of regulated power during the sunlight portions of the orbit.
2. A 0.2-AU solar probe system capable of providing 500 ew of continuous and regulated power.

The design effort has the general goal of optimizing the ratio of power system weight and reliability. The effort will analyze each system in sufficient detail to select basic component configurations and understand component performance and interactions. It will provide engineering drawings, material lists, and functional descriptions of the overall system and system components for the two missions.

A fixed-price contract was obtained with Electro Optical Systems, Pasadena, California, to perform the design. The contract is for $55,000, and work is scheduled to be completed within 6 months. The contract is in its preliminary stages; therefore, activity has been limited. Most of the effort has been concentrated on construction of a comprehensive program schedule. (See Fig. 1.)

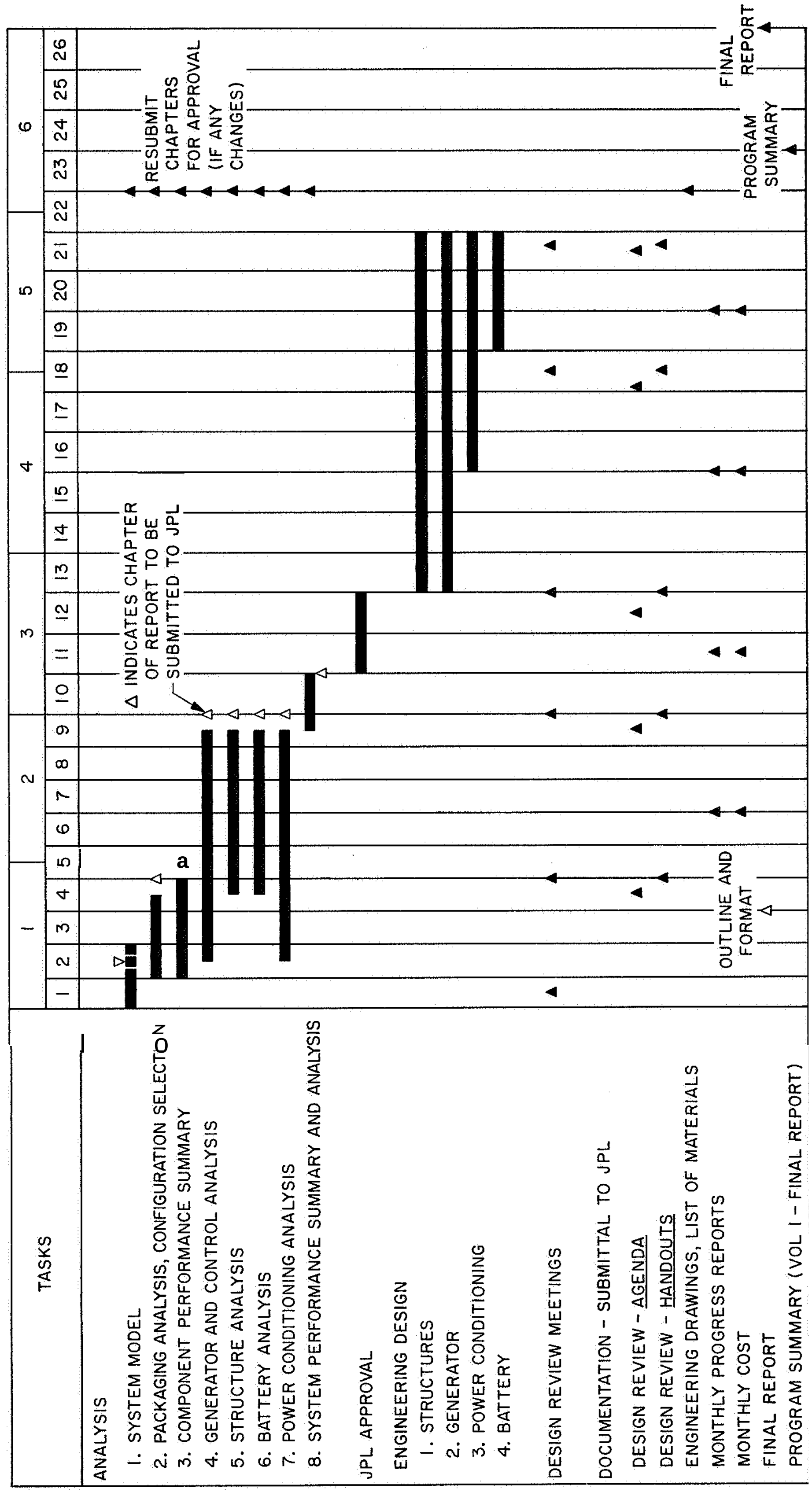

Fig. 1 Program schedule

THERMIONICS SYSTEMS
NASA Work Unit 123-33-06-01-55
JPL 323-30401-2-3420
R. Boring

OBJECTIVE

The objectives of this program include the vacuum coating and testing of a 9.5-ft-diameter mirror fabricated in 1965, the fabrication of 50-in-diameter 55-deg-rim-angle mirrors using the improved mirror-torus attachment techniques developed in the FY 1965 mirror program, environmental testing and evaluation of mirrors using the improved mirror-torus attachment, and related development tasks.

INTRODUCTION

Since the last review period, no new contracts have been initiated. The information presented in this summary will cover the status of those programs noted in the last Semi Annual Report Programs to be discussed include:

1. Secondary experiments.
2. S/N3 9.5-ft-diameter mirror.
3. Cesium reservoir control.
4. Converter procurement.
5. 11.5-ft-diameter mirror.
6. Generator support structures.
7. 5-ft-diameter mirrors.

SECONDARY EXPERIMENTS

The secondary experiment study program was an effort to evaluate suitable space experiments to be performed in conjunction with a spacecraft designed to evaluate solar thermionic power conversion.

This effort is now complete and a final report has been received from Electro Optical Systems, Pasadena, California, the program contractor, The initial program efforts resulted in a list of 100 experiments, and from these 77 were selected for detailed consideration during the remainder of the program. Figure 1 shows the number of experiments considered during the program according to spacecraft subsystems classification. Figure 2 shows a typical power technology payload which was considered for use in this program. The payloads presented in the final report are conceptually laid out within the spacecraft concept established by the General Electric study during FY 1965.

S/N3, 9.5-FT-DIAMETER MIRROR

A 9.5-ft-diameter mirror was contracted to be fabricated with Electro Optical Systems, Pasadena, California. This mirror was to be made from a male submaster supplied by JPL, which EOS had to first refurbish. This replication of the refurbished male submaster was successfully separated, optically checked, and made ready for delivery to JPL on schedule. Figure 3 shows how S/N3 replica compared with the two previous replicas from this submaster. It is interesting to note the weights of each of these replicas and the apparent geometry change after master refurbishing. The high slope error near the rim of S/N3 is the result of edge roll created during the torus attachment.

The 9.5-ft-diameter replica is presently in bonded storage awaiting the availability of a commercial vacuum coating facility. It is expected that this effort will be completed in early 1966. After coating, the mirror will be sent to the JPL Solar Test Facility for test and evaluation in sunlight.

CESIUM RESERVOIR CONTROL

This program is to design, fabricate, package, and test the engineering models of both active and passive temperature control units for use on thermionic converters. At present, the active control is in the breadboard stage, undergoing refinement prior to packaging and tests with actual converters. The passive control is in the design stage. The selection of bimetallic material to use has not been made. After acceptance testing,these devices will be integrated with a thermionic converter and the assembly thoroughly evaluated by JPL.

The active unit is a closed-loop device and monitors temperatures on the converter for the control parameter. The program is currently on schedule, and delivery of the control units is anticipated for February 1966.

CONVERTER PROCUREMENT

In support of the cesium reservoir temperature control, JPL initiated two fixed-price purchase orders for the procurement of suitable thermionic converters to integrate with the cesium reservoir control. Purchase orders were placed with EOS and Thermo-Electron Engineering Corp. (TEECO) for two of each company's latest converter designs. The converters were to be identical to those previously purchased by JPL with the exception that the emitter face would be a flat cylindrical surface, not serrated. Also, a cesium reservoir electrical heater would not be attached. Prior to acceptance, each converter will be performance-tested for 24 hr. The TEECO converters to be used in this program have completed acceptance testing, and one device has been delivered to the cesium reservoir control contractor. The EOS converters are expected to be 4 weeks late for delivery due to a mechanical breakdown in the forging machinery which fabricates the collector-radiator component.

11.5-FT-DIAMETER MIRROR

A program has just been initiated for fabrication of a spin-cast master and a nickel electro-formed replica. Optical inspections will be required both before and after vacuum coating of this mirror with Al and SiO. The contractor, Electro-Optical

Systems, Pasadena, California, is in the initial design stages and is preparing his facilities to handle the entire fixed-price contract ($110,500).

The replica specifications include:

1. Rim angle of 52.5 deg.

2. Two-sigma geometric slope errors of less than 5 min of arc.

3. Total weight, including torus and attachment, to be nominally 350 lb.

4. Reflectance in the visible region of 85% over the entire mirror surface.

This is a 9-mo effort which includes the above mentioned hardware and a detailed final report on the program. This replica will be mounted in the new JPL solar tracker at the Solar Test Facility for test and evaluation. If found acceptable, this mirror will be used to supply thermal power for solar testing of JPL solar thermionic generators.

GENERATOR SUPPORT STRUCTURES

Procurement of two sets of the JPL-designed, fixed-generator support structures was initiated during November 1965. This effort will include some refinement to the design, mainly in the method of generator attachment, and is expected to result in an improved, fixed, coaxial support structure within 3 mo. Upon delivery, mirror/support arm testing is expected to be resumed.

5-FT-DIAMETER MIRRORS

The mirrors to be used in the environmental evaluation of mirror/support arm designs have been delivered to JPL. One of the mirrors weighs 10.6 lb. Optical testing revealed that during separation from the master, the skin was slightly stretched. This stretching, however, had the effect of improving the parabolic geometry of the skin as compared to the master. The skin averaged 0.006 in. thick. The second replica weighed 15.8 lb and showed similar separation effects to those of the lightweight model.

Specifications for these mirrors include the requirements that they have a geometric efficiency of 85% of the master efficiency when using a 0.5-in.-diameter aperture. The geometric efficiency of the master is 93% with a thermal efficiency of 84%. The geometric and thermal efficiencies that were required for acceptance were 79 and 72%, respectively. Both replicas approached 88% geometric efficiency and 79% thermal efficiency when optically measured (thus exceeding the specification) and were accepted.

As soon as fixed support arms are received, an environmental test program utilizing these mirrors is expected to be initiated.

ENGINEERING TECHNOLOGY	POWER	ATTITUDE CONTROL	THERMAL	MECHANICAL	TELECOMM	OPTICAL	SUPPORTING SCIENCE	TOTAL
PRELIMINARY	25	5	5	6	2	0	8	51
SELECTED	19	3	3	3	1	1	8	38
SCIENCE DISCIPLINE	SOLAR PHYSICS	STELLAR AND GALACTIC ASTRONOMY	ATMOSPHERE	IONOSPHERE AND RADIOSPHERE	PARTICLES AND FIELDS	PLANETOLOGY	BIOSCIENCE	TOTAL
PRELIMINARY	15	7	3	5	10	7	2	49
SELECTED	13	5	1	2	13	5	0	39

Fig. 1. Experiment classification

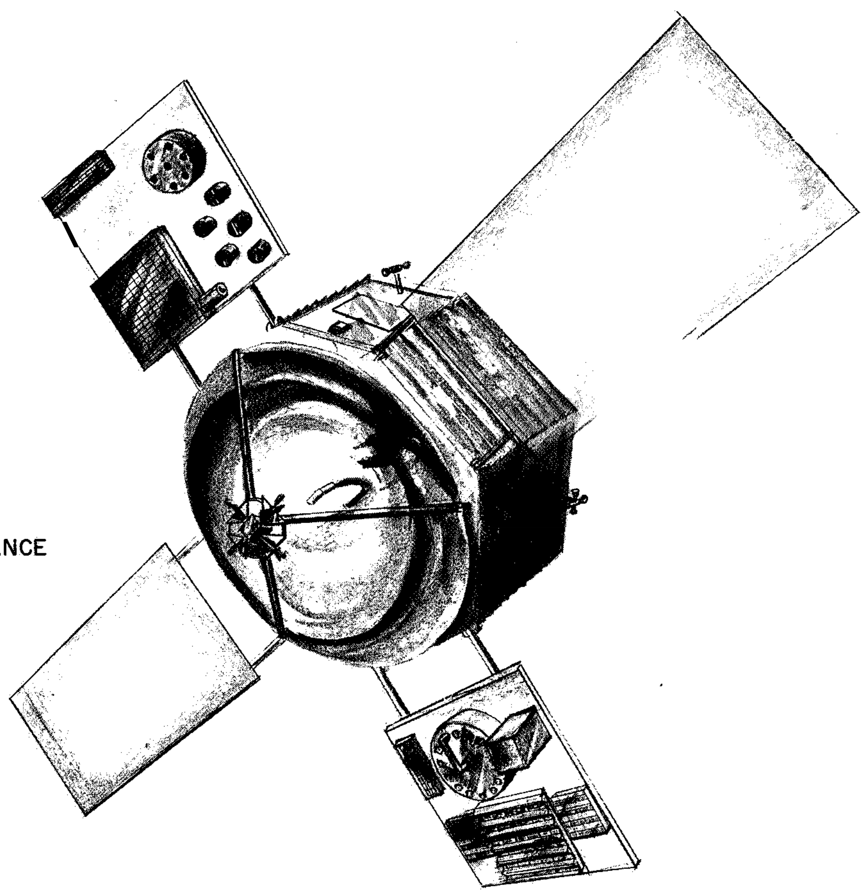

Fig. 2. Typical power technology payload

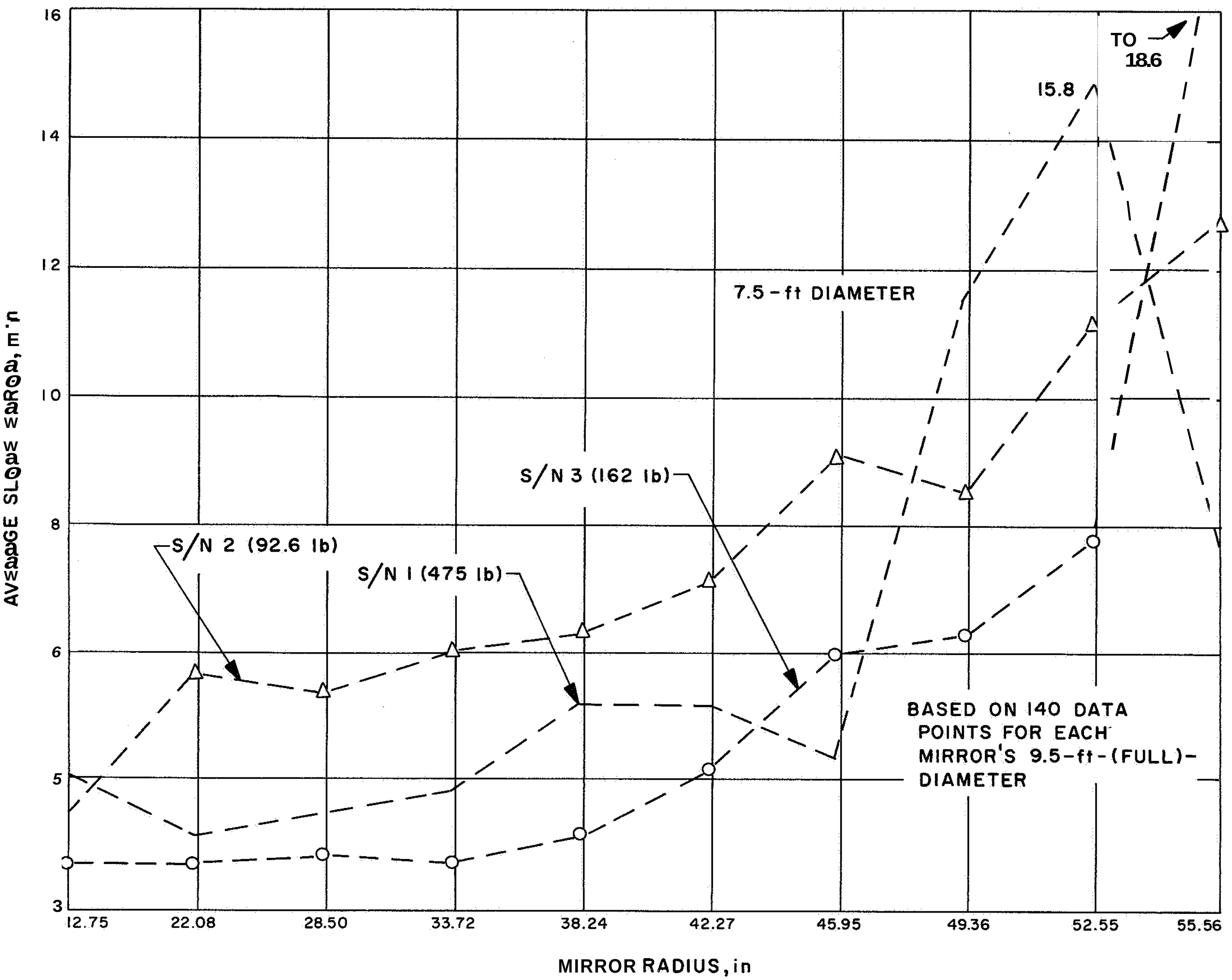

Fig. 3. 9. 5-ft-diameter accuracy

THERMAL ENERGY STORAGE
NASA Work Unit 123-33-07-01-55
JPL 323-30501-2-3420
R. Boring

OBJECTIVE

The objectives of this program are to obtain an operable thermionic converter with a container of bulk 3 BeO - 2 MgO attached to its emitter, to obtain two additional units for demonstration of reproducibility and life, and to investigate techniques to improve the heat transfer characteristics of thermal energy storage materials.

THERMAL ENERGY STORAGE SUPPORTING RESEARCH

This effort is a continuation of the program noted in the last SR/AD report (JPL TM 33-243). The purpose of the program is to measure the thermophysical properties of 3 BeO.2MgO and 4 BeO.MgO.Al_2O_3. During the first half of this effort Battelle has completed measurements of all but two of the seven thermophysical properties desired.

The next six-month effort will be concentrated on determination of phase diagram data and thermal conductivity for these two materials as well as perform a parametric computer study of heat transfer characteristics. It is anticipated that the program will end on schedule in April 1966.

TES FEASIBILITY MODEL

The first Thermal Energy Storage Feasibility Model, built by Thermo Electron Corp., Waltham Mass., was assembled on schedule. Figure 1 is a schematic of the test configuration. After some initial adjustments to eliminate an electrical shorting problem between the model, heater, and shielding, the model was slowly brought to operating temperatures. As the oxide melting temperature was reached a deposit was noticed on the bell jar, The input power to the model was immediately terminated, and upon inspection it was observed that oxide had leaked through the final container weld. Fortunately, the instrumentation monitoring the converter's performance during cool down was attached and operating. The curve in Fig. 2 indicates the effect of thermal energy storage on converter performance. Although not conclusive, this data indicates a specific power of 10.45 w.-hr/lb for eight minutes at 14.4 amperes of constant current for the model. This effort is continuing; improved, more reliable fabrication techniques will be used in manufacturing the second model. This second model is due for delivery in March 1966; if successful the model will be used for extensive performance evaluation and life testing.

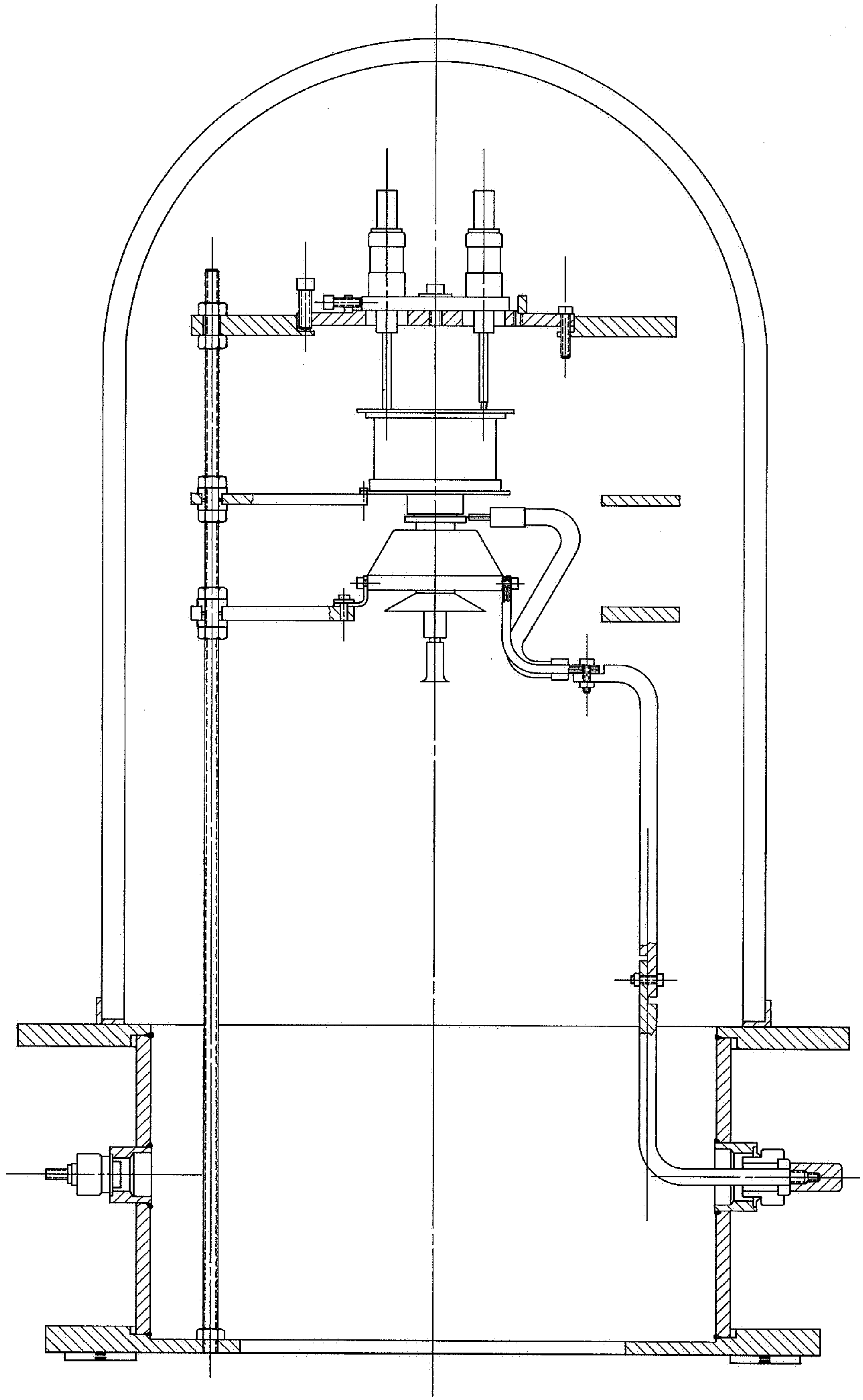

Fig. 1. Test configuration

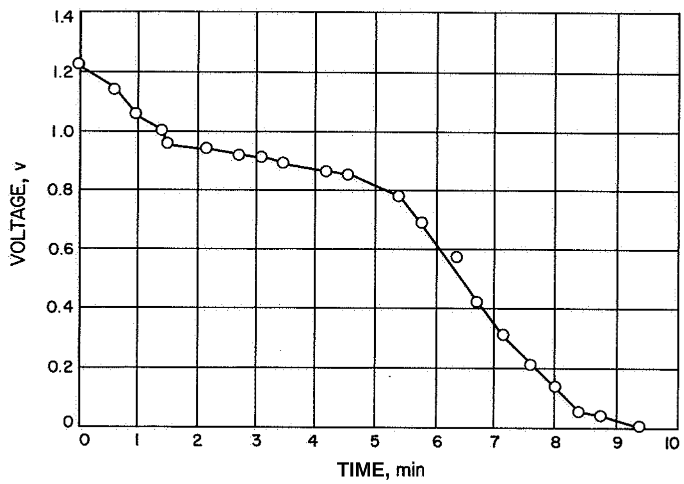

Fig. *2*. Converter performance with thermal energy storage

POWER-CONDITIONING DEVICE DEVELOPMENT

NASA Work Unit 123-33-08-01-55
JPL 323-30301-2-3420
T. Williams

OBJECTIVE

The objective of this program is to develop a store of new electronic devices which will increase deep space power system reliability, efficiency, total power handling capability, and producibility. These devices include an integrated duty-cycle generator, low-loss high-power silicon switching transistors, and low-loss high-temperature thyratrons.

INTRODUCTION

Power-conditioning devices being developed by JPL fall into two general categories. One category involves efficient and reliable switches to be used with low-input voltage converters and inverters. These devices are under development because suitable devices do not presently exist to fulfill the need. The other category is that of microelectronic integrated circuits to be used in the low-level stages of a power-conditioning system. These devices will provide improved system mechanization and reliability, primarily by reducing the complexity and part count. They will also allow reduction of system size and weight.

LOW-VOLTAGE CONVERSION DEVICES

A principal requirement for devices in this category is that they must be capable of rapidly switching large currents with little saturation drop. Secondly, they must operate reliably in a moderately high temperature environment. As reported in the preceding Semiannual Report (JPL TM 33-243, Vol. II, pp. 91-93), out-of-house developments of two different types of switches with these characteristics have begun. One is the development of a high-power, low-saturation-voltage silicon switching transistor. Further reporting of this development is included in the forthcoming JPL SPS 37-36, Vol. IV. The other development is for a high-temperature, zero-drop cesium vapor thyratron operating with cavity thermal power. This development also includes the associated converter circuitry to go with the thyratron.

HIGH POWER, LOW-SATURATION-VOLTAGE SILICON SWITCHING TRANSISTOR

Present Status

Contracts for the first phase of this development were signed with both Westinghouse ($40,987 – eight months) and ITT Semiconductors/Shockley Labs ($73,368 – nine months) in August in a parallel design effort and work has begun. Both companies are investigating approaches whereby the base region and/or the collector region are produced using epitaxial techniques. There are several variations in this type of approach, and each company is using different ones. In addition, Westinghouse is putting some effort into a regular diffusion approach. The results that can be obtained are not quite as good as with epitaxy but may be sufficient, and the overall production cost is less.

The device geometry used by Westinghouse is a star-shaped configuration with the transistor being fabricated on a single large area silicon chip. The design consists of 45 emitter fingers with a total emitter edge length of 21 in. The voltage design and current gain calculations have been completed using computer programs for two different models: (1) simultaneously diffused model and (2) double-diffused model. The simultaneously diffused model can be fabricated by depositing N-type dopant on both sides of a P-type parent material and diffusing on both sides in a single operation. It can also be fabricated by growing a P-type epitaxial layer on an Nt substrate. The N-type dopant is then deposited on top of the P-layer and both N-regions driven into the P-layer simultaneously. For the double-diffused structures, an N-type collector region is grown epitaxially on an Nt substrate. The P-type base and the N-type emitter are then diffused in successive steps. The P-type base can also be grown epitaxially. Three groups of transistors have been fabricated using these techniques and are undergoing evaluation at present. Encapsulation of these devices is by a compression bonding technique in a stud-type package.

Shockley Labs uses an interdigitated comb-type geometry similar to that of a high-frequency power transistor. They are initially fabricating devices of approximately one-tenth the required size to establish suitable epitaxy and diffusion schedules and to check the design theory. The smaller devices will give information on the yield to be expected from larger area chips, so that a decision can be reached on the optimum number of chips in the final device. The basic small device has ten emitter fingers, and yield on the diffusion runs made, to date, has been of the order of 80 to 90%. The collector junction is formed by growing a P-type epitaxial base on an Nt substrate. A phosphorus diffusion is made to protect the junction during subsequent operations. The surface is then masked and etched and the emitter diffusion performed. The results of this technique have been very good. Junction breakdown voltages have been approximately twice the required value. Current gain is slightly low but will increase when the base layer thickness is reduced to the proper value. The devices are presently being mounted on headers so that saturation voltage can be measured. The most serious problem remaining is that of obtaining a suitable large area package for the final device.

Planned Activities

Optimization and evaluation of present designs will continue throughout the development phase of this effort. Alternate fabrication techniques are also under consideration by both companies. Each company will decide upon a final design approach and fabricate a minimum of five developmental transistors for delivery to JPL by May 1966. Evaluation of these units along with individual company performance will result in the selection of one to continue with the production of 100 transistors.

HIGH TEMPERATURE, ZERO-DROP THYRATRON

Present Status

This project is the design study and analysis of a high-temperature, low-voltage cesium vapor thyratron operating with cavity thermal power. Under the proper conditions of cesium vapor pressure and emitter and anode temperatures, it can be made to exhibit a forward drop in the order of zero volts at high current and is capable of being switched. A transformer that can be mounted in the high-temperature zone of a thermionic power system is also to be developed. This eliminates long, high-current paths in the converter with their associated resistive losses. Low-level circuitry can be mounted some distance from the thermal source in a low-temperature zone. Final result of this development is to be a feasibility model of a converter using these devices. The previous SR&AD Report (JPL TM 33-243) lists the required characteristics.

During this reporting period proposals were received from General Electric and Electro-Optical Systems, Inc. They were evaluated, and a one year contract was negotiated with EOS in the amount of $81,000. Work began in late October and, as yet, no results are available to report.

Planned Activities

Phase I of this effort is a 3-mo design study and analysis. It will be completed January 18, 1966. Prior to a formal phase I report, an oral presentation of the study results will be given to JPL representatives. Assuming that the study results show that fabrication of the device is practical, phase II of the development will begin. This is the design, construction, and evaluation of a feasibility model of a dc-dc converter utilizing the results of phase I and lasts 9 mos.

MICROCIRCUIT DEVICES

The use of integrated circuitry can improve present and future spacecraft power conversion systems. Integrated circuitry is smaller, lighter, and more reliable than equivalent circuitry using discrete components. There are limitations to microcircuitry. High-power handling circuits cannot be of the integrated variety because of the large heat dissipation and the large chokes and capacitors required. However, even power supplies require considerable low-level circuitry that suggests microcircuit usage.

At present, JPL is developing two particular microcircuit devices. These are a power synchronizer and an analog voltage to duty cycle generator. The power synchronizer delivers a sync signal to all of the spacecraft inverters. The analog voltage to duty cycle generator performs the low-level functions of a switched regulator. The microcircuit fabrication techniques developed on these devices can be used for other devices.

POWER SYNCHRONIZER

The power synchronizer divides an input frequency signal down to the required frequency and synchronizes the spacecraft inverters. This is the most complex circuit in the power system; it contains 196 parts in its discrete circuit form. The Mariner C synchronizer specification was used as a basis for the requirements of the microcircuit synchronizer. The outputs are 2.4-kc single phase and 400-cps three-phase sync signals. For more versatility, the input signal can be either 38.4 or 4.8 kc. The functional block diagram is shown in Fig. 1. The microcircuit unit contains four silicon microcircuits in one container. These are:

1. A five-bit binary countdown circuit.

2. A three-phase generator.

3. A high-voltage PNP section.

4. A high-voltage NPN section.

Items 3 and 4 are used for the three-phase output circuit.

Each chip contains many circuit elements: transistors, resistors, and diodes. These elements are connected together with deposited aluminum strips. For circuitry of this complexity, these element connections must be multilayered. Single-layer connections are easily obtained, but crossovers have been an industry-wide problem. In early 1962 Westinghouse had devised a method of making crossovers.

A contract was let for $93,209 to Westinghouse in May 1962 to develop the microcircuit synchronizer. As the contract progressed, the crossover yield was too poor to get good microcircuits. In September 1963, Westinghouse had used the funds available attempting to develop a suitable crossover. They continued crossover development on their own funds. In October 1964 this contract was reactivated because the microcircuit synchronizer was still needed, and Westinghouse had demonstrated a capability for solving the interconnect problem. This effort was funded for $77,717.

By September 1965, Westinghouse had developed an interconnect scheme and produced one good five-bit binary (the most difficult chip), as well as sufficient high voltage chips to build the required three units. The packaging technique was developed during this period also.

In November 1965, the contract was funded for an additional $13,295 and extended 3 mo. Most of the increased funding was required because of 1962 and 1963 audited rate adjustments. By February 15, 1966, Westinghouse will produce the required three-phase generators and five-bit binaries, and they will deliver three microcircuit synchronizers and a final report.

ANALOG-TO-DUTY-CYCLE GENERATOR

In every switching mode regulator, there is an error amplifier and a duty-cycle converter (Fig. 2). Complex low-level circuitry is required to perform these functions. A microcircuit device performing these functions is being developed using the techniques developed for the synchronizer. This device can be used in both booster regulators and down regulators. A complete circuit description is contained in JPL SPS 37-35, Vol. IV.

The contract with Westinghouse is funded for $160,000 and is a 12-mo effort started in September 1965. The circuit design is nearing completion and the discrete component breadboard will be thoroughly tested in December. In the period between January and September 1966, the microcircuit design will be completed and the five devices built and tested.

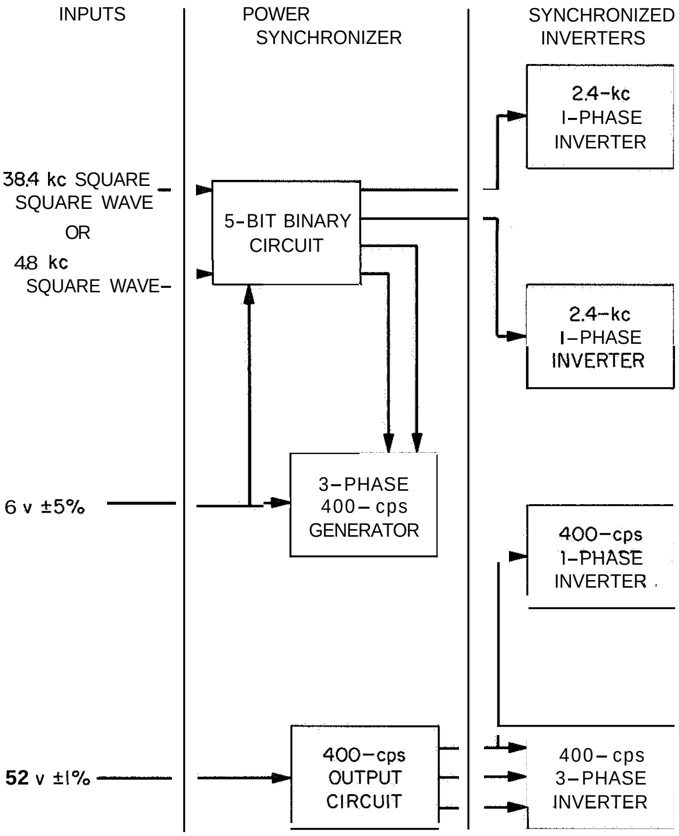

Fig. 1. Power synchronizer functional block diagram

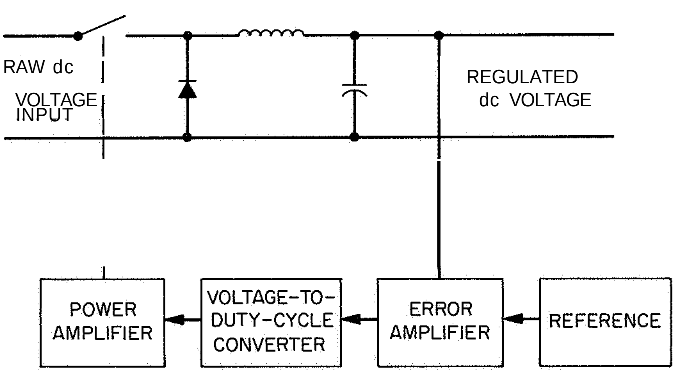

Fig. 2. Switched regulator block diagram

POWER CONDITIONING CIRCUITRY DEVELOPMENT

NASA Work Unit 123-33-08-02-55
JPL 323-31001-2-3420
W. Shubert

OBJECTIVE

The objectives of this program include the development of circuits to alleviate the present problems experienced in space power subsystems in the areas of low voltage converters, battery charging, and power switching, the increase in reliability in subsystems with designs using off-the-shelf microcircuits, and the increase in reliability through design by developing computer-aided worst-case analysis as a design tool.

INTRODUCTION

Power-conversion circuitry development is largely an in-house effort. It can be separated into three categories: the development of circuits for spacecraft with a photovoltaic power source, the development of power-conversion equipment for spacecraft with a thermionic power source, and the development of computer-aided circuit analysis. The battery charger, solid-state switch, and switched regulator are circuit developments using available parts for 25- to 50-v power inputs. The low-input voltage conversion circuits will use the transistors developed in power conversion device development. A final goal of 1.5-to 4.0-v input range is sought. Worst-case computer analysis will allow the engineer to demonstrate design adequacy over environment and component parameter variations.

BATTERY CHARGER DEVELOPMENT

The purpose of this effort is to design and fabricate a battery charger suitable for spacecraft use. It differs from typical spacecraft battery chargers in that each battery cell will be charged separately from a current-limited, constant-potential source. This feature produces a greater uniformity in the cell state-of-charge, resulting in a greater total charge and more reliable battery operation. The goal is to accomplish this capability without a loss in efficiency or overall reliability relative to that now inherent in present chargers.

The battery charger block diagram (Fig. 1) shows the method by which the unregulated input voltage from the solar panels is conditioned to deliver a regulated output of constant potential (using transistor rectifiers for high efficiency) to each battery cell. Provision is made within the battery charger to limit the power input to 20 w.

From the requirements indicated in Fig. 1, a design has been developed and analyzed €or "worst-case" conditions. It has been breadboarded and tested using resistive loading. Load regulation and efficiency tests on the switching regulator and inverter have been performed and the data are now being analyzed.

The remaining task is to test the unit using an actual spacecraft battery. Environmental tests will be performed to confirm the worst-case design. Other switching regulator circuits will be investigated to improve the overall efficiency and reliability.

SOLID-STATE SWITCH DEVELOPMENT

The purpose of the solid-state switch development (refer to JPL TM 33-243 and JPL SPS 37-34, Vol. IV) is to replace the existing motor-driven switch with its attendant problems of weight, size, external field, cost, reliability, and delivery. The circuit is a hybrid approach; that is, a transistor circuit handles the closing and opening transients and limits the voltage appearing across an associated pair of relay contacts during contact transfer to 3 v or less. The relay contacts are closed for the steady-state load and provide a minimum voltage drop.

Since the last report, the design has been analyzed for worst-case conditions. The design has not been environmentally tested nor packaged since a detailed investigation of the design revealed a possible battery current drain, because of transistor leakage, with the switch connected to the battery, but in the "off" state. A redesign was performed and a worst-case analysis repeated to guarantee performance over the temperature range of -10 to +75°C.

In order to eliminate battery current drain, a single rotary stepping relay using rolling contacts is employed. The use of this switch makes feasible the use of more sophisticated circuitry which not only eliminates all drain in the "off" state but also eliminates all drain in the final "on" state. The performance is that of a true mechanical switch. The relay actuation mechanism is immediately available as an off-the-shelf item; the contacts are made to order.

Other necessary changes are to revise the circuitry that senses the condition of 3 v or less appearing across the relay contacts and to modify the ground command circuitry used to actuate the new relay coil.

At this time, the remaining work is to breadboard the complete solid-state switch and to obtain and evaluate test results. The switch will then be packaged and a complete environmental test performed to qualify it for flight use.

Concurrently, a similar development (using silicon control rectifiers instead of transistors) is being performed by Crydom Laboratories.

SWITCHED REGULATOR STUDY

This effort was to be completed during this period, but due to increased demands by programs, there was no manpower available to work on this project. It is now planned to complete the work by June 1966.

LOW-INPUT VOLTAGE CONVERSION TECHNIQUES

This in-house effort is a study of various circuit configurations and conversion techniques suitable for use in low-input voltage power conditioning systems. The present converters are being designed to operate from a 2- to 3-v source, and those designed so far produce power outputs of up to 50 w. Fast switching silicon power transistors are used in the converters. Circuit efficiency is moderately low because of the saturation properties of these transistors, but this can be improved when the transistors described in the Power Conditioning Device Development Section (123-33-08-01) of this report become available. Since, for the purposes of this study, relative efficiency is the important factor, the usefulness of the study is in no way limited.

One converter that has been designed and breadboarded employs a base drive to the power transistors which is proportional to load current. This approach prevents overdriving of the transistors at light loads and provides for greater efficiency at these levels. A switching rate of 5 kc is obtained through the use of a saturable reactor. When parallel combinations of three 2N3597's are used for the power transistors, an output of slightly more than 40 w is obtained at 70% efficiency. The converter will operate down to under 4-w output at an efficiency of approximately 83%. These figures were obtained with a 2.5-v input. Some problems have been encountered with switching transients. These are partly due to mismatching of the power transistors and partly due to stray circuit inductance. These problems are presently being worked out,

A two-transformer Jensen-type converter is presently being breadboarded for testing. In the near future, other types will be investigated, as well as methods of providing output regulations.

COMPUTER WORST-CASE ANALYSIS

Circuit analysis by hand computation is a time-consuming process. It requires many linear approximations of nonlinear circuit elements and, therefore, the accuracy of the result is questionable. With the development of a computer program for general circuit analysis, the design engineer can use the computer to perform his worst-case analysis. The JPL-developed program transient analysis generator (TAG) is a nonlinear circuit analysis program that yields time domain (transient or steady-state) solutions or a dc solution. Alternating current analysis can be handled as a time-domain problem with the proper driving function.

For this program to be useful in power conversion circuit analysis, nonlinear models of the solid-state components used and magnetic component models must be developed, and the TAG program must be in a form that engineers can use. A contract was let to Mesa Scientific Corporation to develop models and to familiarize power conversion personnel with computer operations and the TAG program.

Nonlinear equivalent circuits have been developed for transistors, diodes, tunnel diodes, zeners, and silicon-controlled rectifiers. Work is progressing on a component modeling handbook. A library of parameter data for specific component types will be assembled, including parameter variations within each type for use in worst-case analysis.

A piecewise linear saturating core model has been developed, and work is progressing on a model that includes hysteresis. Considerable development is required before the core model is representative of the real component.

To obtain understanding of the TAG program, several nominal case circuits have been analyzed by the power conversion group engineers. These are: an L-C filter with a square wave input and sine wave output, two 38.4-kc transistor oscillators, and a series regulator. The computed circuit performance for all the circuits agrees closely with Laboratory data. In one oscillator program, the circuit component values and transistor parameter values will be varied to worst-case extremes. The variation of the computer-calculated oscillation frequency will test the worst-case analysis capability of the TAG program.

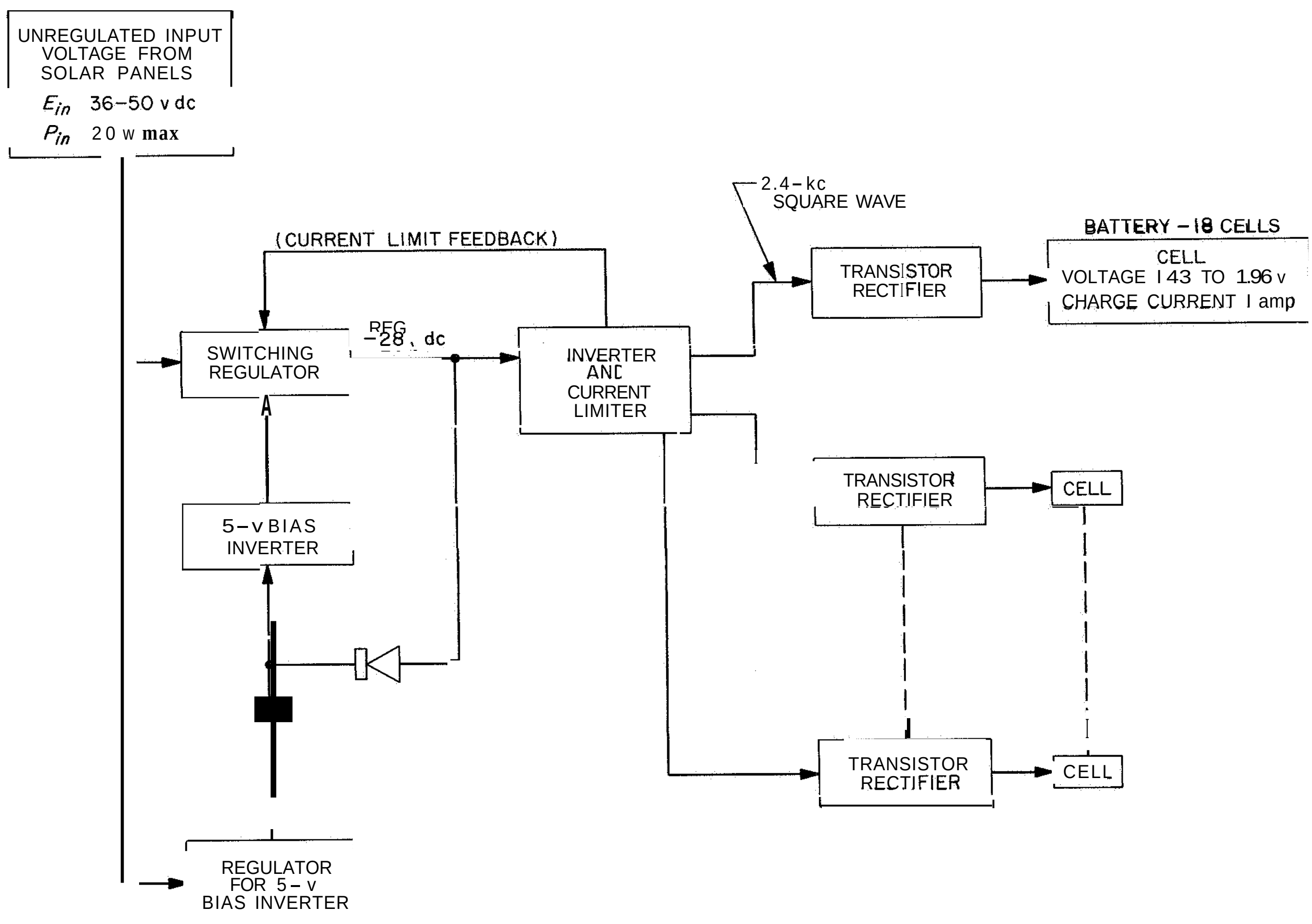

Fig. 1. Battery charger block diagram

CHEMICAL POWER GENERATION (123-34)

ELECTROCHEMISTRY OF BATTERY ELECTRODES
NASA Work Unit 123-34-01-01-55
JPL 323-40101-2-3420
A. Uchiyama

OBJECTIVE

The objectives of this program include the study of reaction geometry in the oxidation and reduction of alkaline electrodes, the investigation of the chemical and electrochemical nature and behavior of electrodes, the determination of the state of charge of alkaline batteries, and the advance in the state of the art of remotely activated battery systems. Primary emphasis will be directed toward long life space missions in radiative and reduced gravity environments.

INTRODUCTION

This work is directed toward achieving an understanding of the basic electrochemical phenomena associated with radiation effects and reaction geometry on electrode surfaces.

RADIATION EFFECTS ON BATTERY ELECTRODES

Ni-Cd System

A manuscript titled "Effects of Gamma Radiation on the Behavior of Nickel and Cadmium Electrodes" by Drs. G. R. Argue, H. L. Recht and G. M. Arcand was submitted for publication in the Electrochemical Technology Journal. The data for the paper was generated under JPL Contract 950514 with Atomics International, a division of North American Aviation.

Ag-Zn System

This work is being performed under JPL Contract 951109 with Atomics International, a division of North American Aviation. A supplemental agreement is presently being processed in order to carry on further work for another year. An interim report covering the work from July to October 1965 has been issued and is titled "Radiation Effects on Silver and Zinc Battery Electrodes."

Data from this study indicate that radiation causes material loss from the silver electrode. The magnitude of the loss appears to be a function of the state of charge of the silver electrode. The results are summarized in Table 1.

Hydrogen evolution occurred during cell irradiation; none was formed in the unirradiated cell.

Considerable scatter was observed in the silver electrode capacity data, and both capacity increases and decreases were observed depending upon the state of charge. These effects were observed in the dose range studied, approximately 10^{+8} rad (H_2O).

Table 1. Summary of silver electrode material loss data

State of charge, %	Average weight of sloughed material,* mg	
	Irradiated cell	Control cell
90	60.2 ±10.5	11.9 ±3.3
60	77.7 ± 3.3	22.7 ±3.9
30	52.9 ± 1.9	22.4**

REACTION GEOMETRY OF THE SILVER ELECTRODE

This work is being performed under JPL Contract 951157 with the Brigham Young University, Dr. E. A. Butler, principal investigator. The work during this period has been directed primarily to two problems: (1) determination of effective electrolytic surface area on silver plates and (2) measurements of the potential over the silver electrode surface during charge.

While the surface area of a sintered silver plate can be measured by various techniques, it would be far more valuable to be able to make the measurement by a technique which depends upon electrolytic reaction since the area effective in such reaction is the important area in controlling current densities. It appears that there is a good possibility of making a reasonable estimate of the effective electrolytic area.

Experimental work is continuing on the measurement of potentials at specific regions of the electrode. The consistently higher potentials at the edge of the plates is especially interesting in light of the fact that a silver sheet electrode charged at low constant current density shows more rapid darkening near the edge and leaves a center region of distinctly different appearance.

ELECTROCHEMISTRY OF BATTERY ELECTROLYTES AND SEPARATORS

NASA Work Unit 123-34-01-02-55
JPL 323-40201-2-3420

Ralph Lutwack

OBJECTIVE

The objectives of this program include the study of the chemistry of concentrated electrolyte solutions, the measurement of the transport of chemical species in concentrated solutions and through membranes of the types used in batteries, the study of the permeability characteristics of membranes, the investigation of the reaction of silver ions with cellulose, the determination of the effect of electrolyte displacement in battery performance, the investigation of separator hydrophillicity on electrode performance, and the study of the effect of the rate and method of electrolyte absorption on battery performance.

INTRODUCTION

This program is directed toward a rigorous study of ionic transport through membranes, which is to be used to define the permeability characteristics of battery separators.

ACTIVITIES

A contract sponsored jointly with the Office of Saline Water is under way with the National Bureau of Standards (Dr. Blanton Duncan being the chief investigator) to carry out a detailed theoretical and experimental application of the thermodynamics of steady-state processes to the investigation of transport phenomena at junctions between electrolyte solutions. In particular, the permeability characteristics of membranes in contact with multicomponent electrolyte solutions will be studied.

The program comprises eight tasks:

1. The principles of the theoretical description will be tested, the measurements being made on a single membrane under well-defined conditions.

2. The apparatus for the measurements will be refined to provide a more efficient instrument.

3. Tests will be made of the maintenance of linearity and reciprocity as functions of displacement from equilibrium.

4. The dependence of membrane properties on membrane material and structure will be studied using a nine-element impedance material for each membrane.

5. The variation of permeability characteristics as a function of the cationic constituent of the solution will be studied.

6. The variation of permeability characteristics as a function of varying concentrations of NaCl-KCl solutions will be studied.

7. The linear interaction coefficients will be studied to permit an analysis of membrane transport characteristics through resolution of the total resistance to movement of a constituent into terms arising from interactions with other constituents.

8. Attempts will be made to extend the treatment to displacements of acid-base and other equilibria as driving forces or to include partial ionization in defining flows.

In these studies the phenomenological relations, which are the most useful in the designed experiments, are the following:

$$J_v' = h'\Delta P - \theta'\theta_s \Delta \log m + e' I/F$$

$$J_D' = f'\Delta P - d'\theta_s \Delta \log m + t' I/F$$

$$-F\Delta\phi = s'\Delta P + p'\theta_s \Delta \log m + r' I/F$$

Here, J_v' is the rate of flow of fluid volume through the membrane, J_D' is the rate of flow of salt with reference to water through the membrane, $-F\Delta\phi$ is the potential across the membrane, ΔP is the pressure difference across the membrane, $\Delta \log m$ is the logarithm of the molality ratio of the solutions on the two sides of the membrane, I is the rate of flow of electric charge across the membrane, and h', θ', e', f', d', t', s', p', and r' are the phenomenological coefficients. The meaning of each coefficient can be ascertained from the differential equations.

Tasks 1, 2, 3 are now being done. A large amount of data has been obtained and is being evaluated.

SPACE VEHICLE SYSTEMS (124)

SPACECRAFT AEROTHERMODYNAMICS (124-07)

PLANETARY ENTRY GAS DYNAMICS

NASA Work Unit 124-07-01-01-55
JPL 324-71401-2-3530
T. E. Horton
H. J. Stumpf
F. Wolf

STAGNATION POINT CONVECTIVE HEAT TRANSFER – T. E. Horton

As part of our continuing study of stagnation point heat transfer, an experimental investigation was undertaken in cooperation with the Aerodynamic Facilities Section. The first phase of this work, which is directed toward assessing the effect of atmospheric composition on stagnation point convective heat transfer, was reported in Ref. 1. Data from this investigation revealed a higher heat transfer rate in a mixture of 6570 CO_2 and 35% Ar than had been observed in other diatomic-triatomic mixtures.

Uncertainties in the previous results (due to radiative heating of the colorimeter heat transfer gage) as well as the desire to examine other gas mixtures led to another series of experiments which have just been concluded and will be reported in Ref. 2. The results of this investigation indicate an increase in heat transfer in the atmospheric mixtures containing large amounts of argon for the flight range where ionization becomes significant. For a mixture of 30% CO_2 - 40% N_2 - 30% Ar the increase, above the values obtained in air, was about 10%; while for the 6570 CO_2-35% Ar mixture the values of heat transfer were about 25% above those in air and 15% above theoretical values for this CO_2 - Ar mixture However, in the Martian entry range below 25, 000 ft/sec, ionization is not significant, and heat-transfer rates are similar to those in nonargon atmospheres.

Analytical work on the effect of transport properties on stagnation point convective heat transfer is continuing.

EQUILIBRIUM SHOCK LAYER RADIATION – F. Wolf

The correlation of experimental data with analytical methods for shock layer equilibrium radiation in the stagnation region of entry bodies continued during this report period. Experiments in the JPL, General Electric and NASA Ames facilities, covering Mars atmospheric models of varying chemical compositions are summarized in Ref. 3 and 4, with theoretical intensity calculations utilized to reduce the two parameter experimental data into functional forms. The density dependence of gas radiance was found to depend noticeably on both the enthalpy (or flight velocity) and the thermochemical properties of the gas, which determine the equilibrium composition behind a moving shock. The scarcity of data on gas radiance at relatively low free stream density (see Ref. 4) is due to the approaching limit of the radiation gauge sensitivity. This situation will be relieved by a set of shock tube runs under preparation at present at G. E. and will extend the covered area shown in the summary graph of Ref. 4 toward the lower density region. These tests are performed with the side wall observation method, which provides a stronger signal and minimizes the effects of nonequilibrium radiation on the measured gauge output.

A study has been underway since September 1965 to determine the effect of the simplifying techniques on heat transfer distributions. The initial phase of this effort was directed towards examining the existing flow field computational methods for an inviscid gas in equilibrium. Two broad classes of problems are treated in the literature; the inverse method in which a shock shape is assumed and a body shape computed and the direct method in which the body shape is given and the shock shape determined. The first approach is typified by the method of Van Dyke and the second by the integral relations technique of Dorodnitsyn or the procedure of Gravalos, Edelfelt, and Emmons. Although the inverse technique is computationally simpler it has several major disadvantages. The first is that the shock shape corresponding to a particular body shape is not known a priori; secondly, small variations in the shock shape may result in large changes in the body shape; and finally the method is not well suited to bodies with sharp corners or sudden changes in curvature. Most of the recent work on inviscid equilibrium flow field calculations employs the direct method of Dorodnitsyn or Gravalos.

The effort for the remainder of FY 1966 will be devoted to investigating the available flow field computational techniques for equilibrium flow including the effects of coupling between the convective and radiative heat transfer modes and the flow field. It is known that the coupling between the convective and radiative heat transfer processes will in general reduce the convective heating rate more than can be accounted for by considering the fact that the driving enthalpy for convective heating has been diminished by the emission of radiant energy from the shock layer. In addition the heat transfer processes modify the flow field; in some instances, particularly at the stagnation point, the usual technique of separating the shock layer into an inviscid outer layer and a boundary layer may not be justified.

Calculations using a more sophisticated flow field model will be made to verify the results obtained from the AVCO program.

REFERENCES

1. Collins, D. J., and Horton, T. E., "Experimental Convective Heat-Transfer Measurements," AIAA Journal, Vol. 2, pp. 2046-2047, November 1964.

2. Horton, T. E., and Babineaux, T. L., "Experimental Assessment of the Effect of Large Amounts of Argon in Planetary Atmosphere on Stagnation-Point Convective Heating," presented at the AIAA 3rd Aerospace Sciences Meeting, New York, January 26, 1966. (AIAA paper 66-29).

3. Spiegel, J. , and Wolf, F., JPL SPS No. 37-33, Vol. IV, pp. 99-103.

4. Wolf, F., JPL SPS No. 37-36, Vol. IV.

However, several intensity peaks in the spectral distribution are approaching the black body limit and thus are strongly self absorbent. G. E. has attempted to correct this difficulty by the use of splitter plates in the 6-in.-diameter shock tube and also analytical determination of spectral absorption coefficients for a theoretical reduction of the data to the nominal values of an optically thin gas.

Curve fits to the accumulated data on intensity of equilibrium radiation to satisfy requests for approximate analytical expressions to be used in entry heat transfer computer programs still have to contend with an uncertainty factor of approximately two in the recommended radiation intensity values.

The distribution of radiation heat transfer over the surface of an entry body is needed for thermal design of entry vehicles. To obtain comparative data on a number of entry body shapes a contract has been let to the AVCO Corporation for the determination of the total radiative heat transfer to three forebody shapes and two aftbody shapes under simulated Martian entry conditions. Since comparative methods, aiming at the selection of advantageous geometrical capsule configurations are the main purpose, the tests will be limited to one atmospheric model, a flight velocity range from 15,000 to 26,000 ft/sec and three angle-of-attack settings. Both shock tube and ballistic range experiments are provided for adequacy in scaling the model test results to prototype dimensions.

NONEQUILIBRIUM RADIATION

Sample calculations for a Mars entry body of 18.5-ft diameter, based on a trajectory in model atmosphere VM-1 (5mb surface pressure), an entry path angle of -38 deg and an entry velocity of 22,000 ft/sec indicate large nonequilibrium radiation effects in the stagnation region of a spherically blunted conical shape, including effects of truncation. However, at the capsule outer regions, which are most important from a heat shield weight standpoint, equilibrium radiation is dominant.

Nonequilibrium radiation data are obtained concurrently with the work on equilibrium radiation under our contract with G. E. that is expected to be completed within the next half of this fiscal year.

SIZE EFFECT AND FLOW FIELDS – H. J. Stumpf

It is known that increasing the size of an entry vehicle with fixed shape depresses the convective heat transfer mode and intensifies the equilibrium radiative heat transfer mode. Analyses of these heat transfer modes often use simplifying assumptions (such as optically thin and isoenergetic shock layers) that may lead to appreciable errors in heat shield weight estimates.

The AVCO Corporation under JPL Contract 951070 has devised a series of computer programs intended to screen the range of design parameters which significantly influence the choice of vehicle shape and the calculation of the heat shield, structural, descent, and landing system weights, It is not intended as a detail design tool and programming compromises were necessary in order to avoid excessive computation time and wasteful generation of information not directly usable for the problem at hand. Program 1885 of this series computes the laminar and turbulent convective heating distribution and the radiative heating distribution for arbitrary angle of attack. Because relatively simple analytical techniques are employed, the program has certain limitations.

HYPERVELOCITY LABORATORY
NASA Work Unit 124-07-01-04-55
JPL 324-70800-2-3730
F. R. Livingston

OBJECTIVE

The long-range objectives are to provide experimental aerothermodynamic support for the JPL planetary entry projects. The supports consists of performing (1) Hypervelocity Laboratory operations, (2) aerothermodynamic studies, and (3) gasdynamic flow studies.

HYPERVELOCITY LABORATORY OPERATIONS AND DEVELOPMENT

The JPL 6-in.-diameter electric-arc-driven shock tube has been in operation for almost 4 yr and has produced valuable data in the study of convective and radiative heat transfer. A total of 120 runs were obtained in this facility during the reporting period. This facility is described in detail in Ref. 1 and is shown in Fig. 1. A new test section, Fig. 2, was installed and provides 18 additional instrument ports. To extend the shock speed and test time capabilities of the facility, a new driver (now being fabricated) was designed, and more capacitors were purchased.

The development of the free piston shock tube (Ref. 2) has been in two phases: (1) performance evaluation of the shock driven tube and (2) evaluation of the shock tube system, i.e., driver-driven tube coupled with diaphragm opening. The shock tube is shown in Fig. 3. Final pressure and temperature data were obtained for initial driver pressures of 2, 5, and 10 psia and are presented in Fig. 4 and 5 (Ref. 4).

The second phase of the facility development – i.e., evaluation of the shock tube system – is contingent upon diaphragm burst tests now in process. The results of these tests will determine the proper diaphragm design for the various conditions being measured in the driver. Some results have been obtained at lower final driver pressures (<2000 psia) where diaphragm design criteria are known. Fourteen runs were made into air at initial pressures of 0.25, 0.10, and 0.05 mm Hg, and a shock speed range of 15,000 to 22,000 ft/sec was obtained (Ref. 3). The operational effort for work done on this facility totaled 146 runs during the reporting period.

A modification to the facility has been to add 8000 lb of mass in an effort to correct vibrations caused by the recoiling action of the driver. Also, the piston configuration has been redesigned to avoid costly Teflon spraycoating of the piston and to eliminate as much Teflon surface area exposed to heat as possible. It is hoped that this new piston will reduce driver gas contaminants and wear better; fabrication should be completed in February 1966.

The 43-in. shock tunnel was designed for operation at Mach number 12 from the reflected region of a 6760 ft/sec incident shock propogated into 12.5 cm Hg of air in the 3-in.-diameter shock tube. Unheated hydrogen is used as the driver gas in the shock tube. A photograph of the nozzle is shown in Fig. 6. Tests during the latter half of the year were concerned with (1) determining the shock tube tailored conditions with hydrogen driving nitrogen test gas and (2) shakedown of the tunnel and pitot pressure rake system.

AEROTHERMODYNAMIC STUDIES

Total radiation measurements were made at the stagnation point of a flat faced model over the temperature range 9000 to 15,000° K. These results are presented in Fig. 7. Further total radiation measurements will be made in which appropriate photomultipliers will be used to identify the source of the observed excess radiation. The spectal radiation at 5000Å was measured over the same temperature range, and the results are presented in Fig. 8.

A program has recently been initiated at the JPL to make a spectroscopic investigation of planetary gases in the vacuum ultraviolet region of the spectrum as reported in Ref. 5. Several important sources of radiative heat transfer to planetary vehicles are believed to exist in this spectral region. In order to make these measurements, a grazing incidence vacuum ultraviolet spectrograph was designed and built at JPL (Fig. 9). This instrument is presently undergoing checkout in preparation for a quantitative calibration which will be made using a hollow cathode discharge souce.

Several techniques have been developed at JPL for making quantitative radiation measurements in shock tubes and have been reported in Ref. 6. These techniques include methods for measuring total radiation using carbon-coated thin film gages. Methods for calibrating the gage and of relating the gage response to the source radiance were developed. A photographic technique employing a rapid shutter for time resolution allows the measurement of shock standoff distance for shock tube models. Prism and grating monochromators have been adapted to the shock tube in order to make photometric studies of oscillator strengths, relaxation times, nonequilibrium and equilibrium radiation, and chemical rate constants in the 2000 to 10,000 Å spectral region.

Calibration techniques for the visible and near ultraviolet wavelength regions have been developed. A typical calibration spectrogram obtained using a pyrometric carbon arc source is shown in Fig. 10. This spectrogram shows the rotational line structure of the CN violet band system which is of current interest for the problem of Mars entry. The carbon arc has been developed as a reliable standard for absolute intensity calibration of spectrophotometers used in current shock tube studies in the near ultraviolet region. A comparison of the carbon arc intensity and that of a standard tungsten source is shown in Fig. 11.

Preliminary studies of techniques for eliminating stray (scattered) light in the ultraviolet spectral region were investigated. Methods employed were: filters, flourescent sensitized coatings, and "solar blind" photomultiplier tubes. An EMR solar blind tube has been used with a grating blazed at 3000Å to measure gas radiation from the shock tube at wavelengths down to 2000Å.

An experimental investigation (Ref. 7) was conducted to assess the effect of significant amounts of argon on stagnation point convective heating (Fig. 12). The data were obtained utilizing the JPL arc-heated shock tube with a 6-in.-diameter driven section to simulate flight velocities in the range of 18,000 to 34,000 ft/sec. The thermodynamic properties behind the incident and model bow shocks were calculated for the various mixtures. Using these data, the convective heating results were corrected for the estimated radiative contribution to the data.

A brief study was made to assess the problem of simulation of the energy balance to a typical Voyager capsule on the Mars surface. The energy balance will be determined by the following factors:

1. Forced convection due to wind velocity and temperature.
2. Radiation consisting of the incoming solar radiation and the exchange of infrared radiation between the capsule and the Martian environment.
3. Conduction of heat to the ground.
4. Heat generated by internal power systems.

Due to the considerable uncertainties in wind velocity and temperature, temperature of the Martian surface, as well as uncertainties in the physical features of the Mars terrain, the problem was studied parametrically in terms of these unknowns,

GAS DYNAMIC FLOW STUDIES

The shock speed and test time performance of electric arc-driven shock tubes is not well understood at the present time. Experimental data were correlated on the basis of the ideal shock tube theory and the wall-boundary-layer theory. The study resulted in the formulation of empirical rules to aid the electric arc-driven shock tube designer. The results of this work (Ref. 8) show that for gas radiation studies, the required dimensions of the shock tube increase with increasing shock speed and decreasing initial test gas pressure, but not in a manner expected from consideration of the wall-boundary-layer theory alone.

Tests were conducted in the 3.089-in.-diameter shock tube to determine the magnitude of the air boundary layer displacement thickness parameter, β, at low initial air pressures. The results of these tests (published in Ref. 9) are in agreement with laminar wall boundary layer theory at pressures greater than 150μ Hg. Contrary to expectations, however, the trend and magnitude of the measured length of the hot gas sample below initial air pressure of 150μ Hg tend to agree with the turbulent-wall boundary layer theory (see Fig. 13). No explanation for this phenomenon has been found.

In order to better interpret shock tube and shock tunnel model tests, we require a numerical blunt-body flow field computer program to describe the flow around aerodynamic bodies of interest. The numerical data obtained from the flow field analysis will be used to interpret radiative and convective heating tests, and electromagnetic propagation experiments. A literature review has been made to become familiar with existing methods. Since our immediate concern is with inviscid, adiabatic, equilibrium flow over various blunt bodies, the method selected for detailed study is the Dorodnitsyn Belotserkovskii direct method of integral relations.

CONTRACTS MONITORED

A consultant was employed to perform analytical gas radiation studies (JPL P.O. AX-368546). The initial tasks being performed are studies of free-bound radiation, atomic line radiation, and molecular radiation pertaining to planetary entry heating problems.

All shock tube data reduction for shock speed and radiation measurements have been successfully performed under a contract (JPL P. O. A5-327138) by Northrup Space Laboratories data reduction subunit. This work involves digitizing data from poloroid films. The data are then reduced to final form using a computer.

MEETINGS

The "Fourth Hypervelocity Techniques Symposium" held at AEDC, Tullahoma, Tennessee was attended in support of this task.

REFERENCE

1. Collins, D. J., Livingston, F. R., Babineaux, T. L., and Morgan, N. R., "Hypervelocity Shock Tube", JPL TR 32-620, June 15, 1964.

2. Babineaux, T, L,, and Riale, B. R., "Theory and Performance of a Free Piston Shock Tube Driver" (to be published).

3. Riale, B. R., and Babineaux, T. L., "Performance Evaluation of a 12 in. Diameter Free Piston Shock Tube," JPL SPS No. 37-25, Vol. IV.

4. Babineaux, T. L,, and Riale, B. R., "Preliminary Performance of a Free Piston Shock Tube," JPL SPS 37-34, Vol. IV, June-July 1965.

5. Thomas, G. M., "Ultraviolet Radiation Program at JPL," Fluid Physics Research Program in Ultraviolet Radiation, NASA Research Division Office of Advanced Research and Technology, Washington, D. C., August 31, 1965.

6. Menard, W. A., and Thomas, G. M., "Radiation Measurement Techniques," proceedings of the 5th Shock Tube Symposium, American Physical Society (to be published).

7. Horton, T. E., and Babineaux, T. L., "Experimental Assessment of the Effect of Large Amounts of Argon in a Planetary Atmosphere on Stagnation Point Convective Heating," to be presented at the AIAA Third Aerospace Sciences Meeting, January 24-26, 1966.

8. Livingston, F. R., "Electric Arc-Driven Shock Tube Diameter, Length and Energy Requirements for the Study of Gas Radiation Phenomena" proceedings of the 5th Shock Tube Symposium, American Physical Society (to be published).

9. Livingston, F. R., and J. Lerner, "Indirect Measurements of the Boundary Layer Displacement Thickness in the 3-in. -Diameter Shock Tube," JPL SPS No. 37-34, Vol. IV.

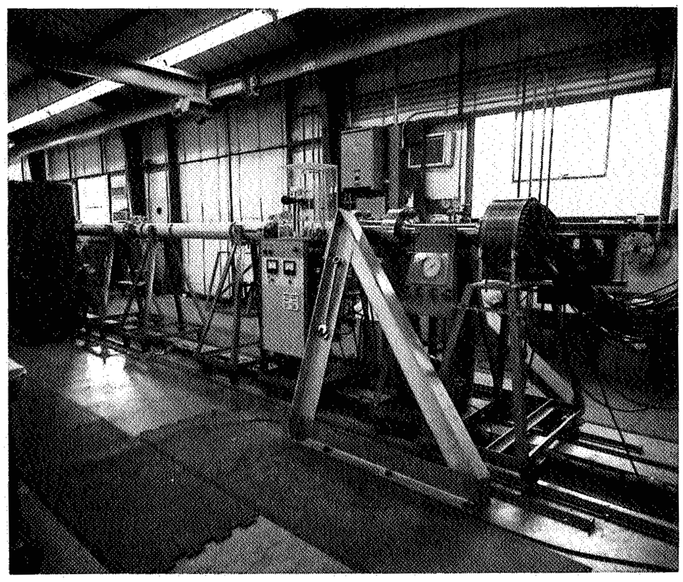

Fig. 1. 6-in.-diameter electric shock tube

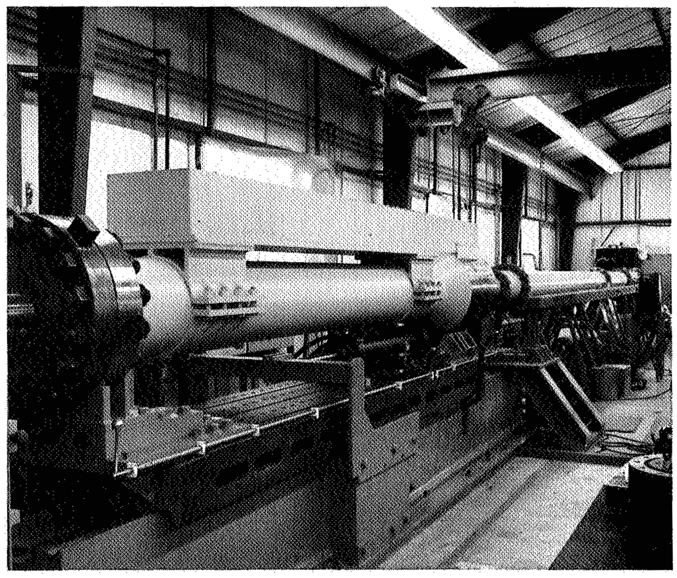

Fig. 3. JPL free-piston shock tube

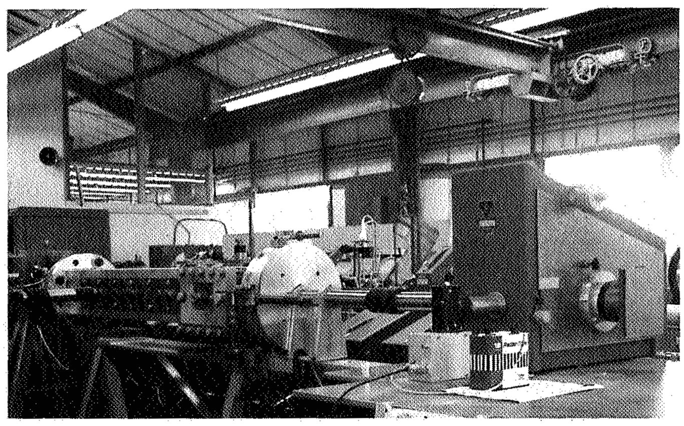

Fig. 2. New test section

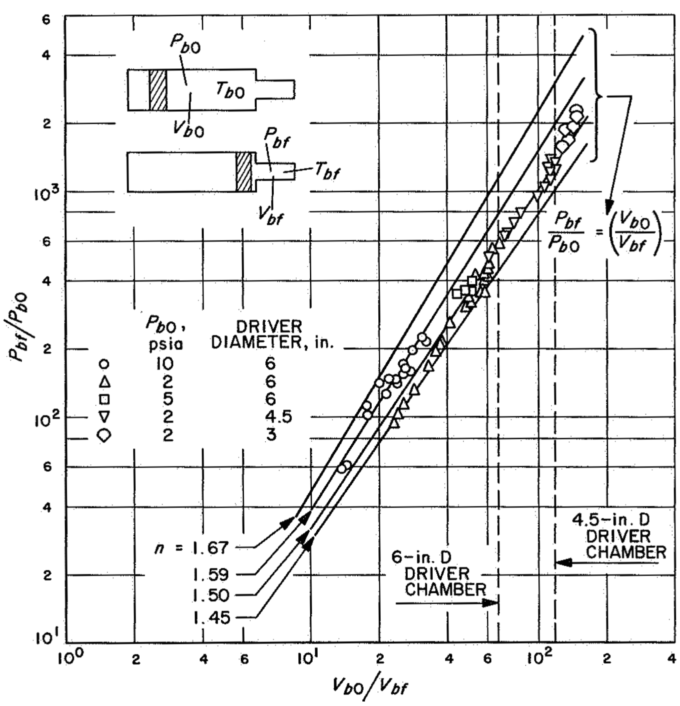

Fig. 4. Final pressure in the driver as a function of volume

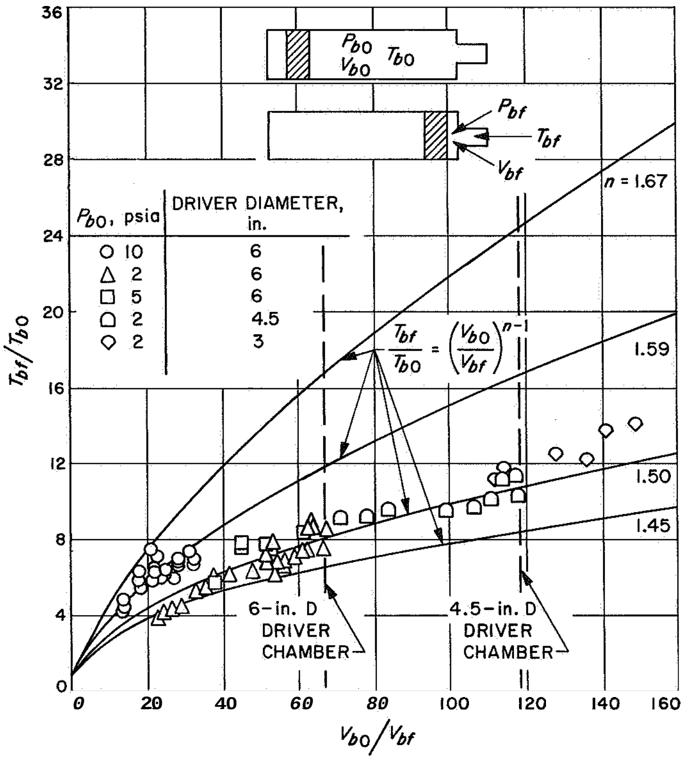

Fig. 5. Calculated temperature ratio of compressed helium in the driver based on measurements of V_{b_f} and P_{b_f}

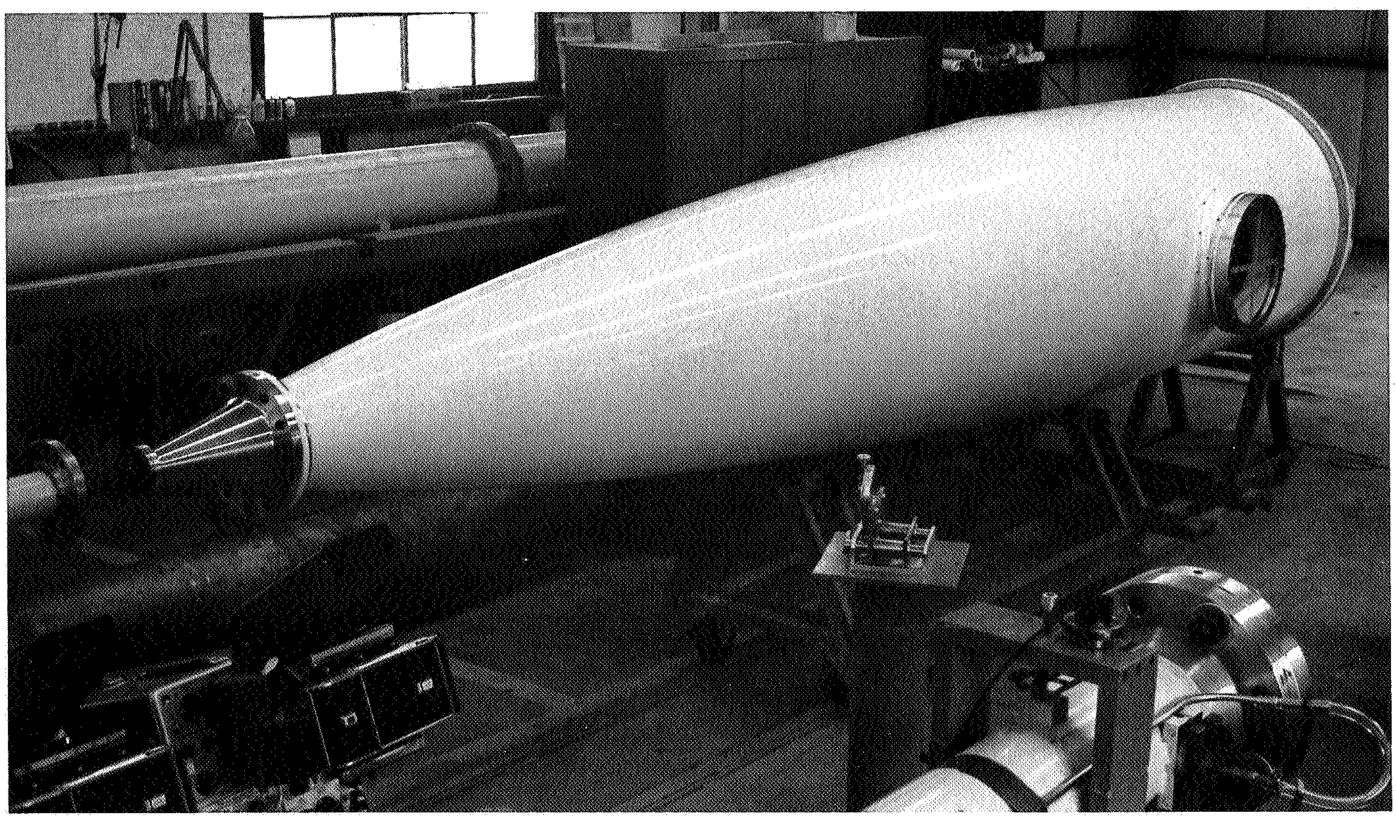

Fig. 6. 43-in.-diameter shock tunnel

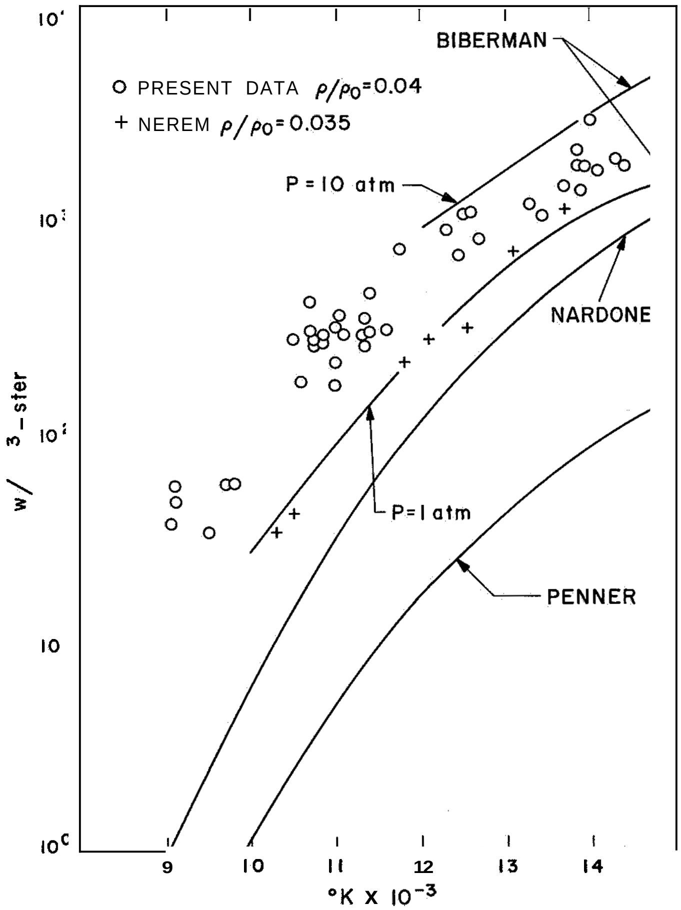

Fig. 7. Equilibrium total radiation data for the wavelength region 0.3 to 3μ. (The results are compared with existing data and various calculations discussed in the test.)

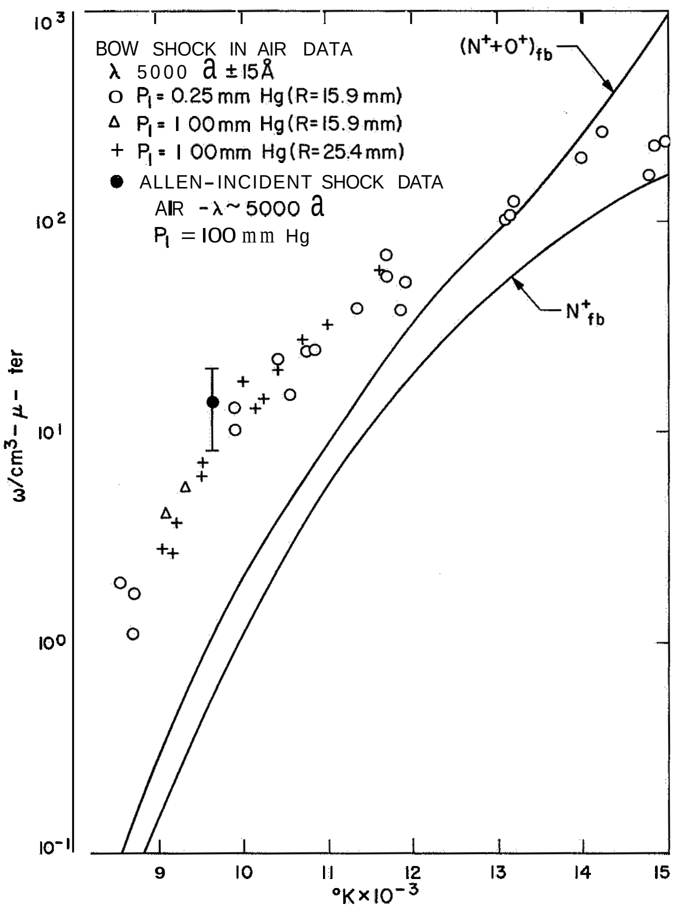

Fig. 8. Measurements of the continuum radiation at 5000A for two initial pressure conditions and two model nose radii. (The theory lines are discussed in the text.)

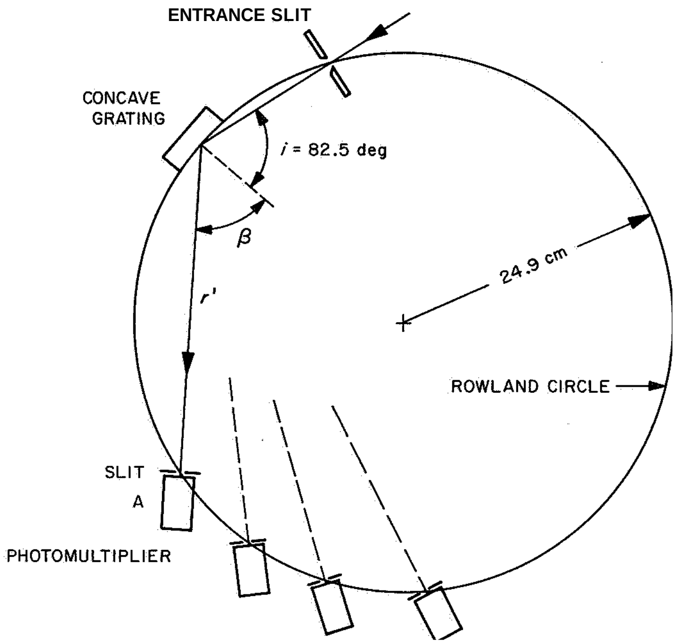

Fig. 9. Schematic showing optical layout of vacuum ultraviolet spectrograph

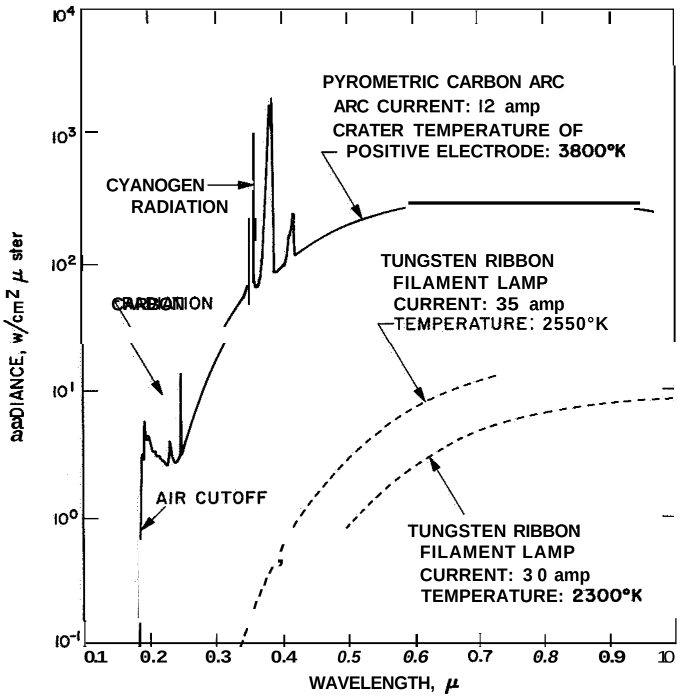

Fig. 11. Spectral radiance of typical carbon arc and tungsten lamp calibration sources

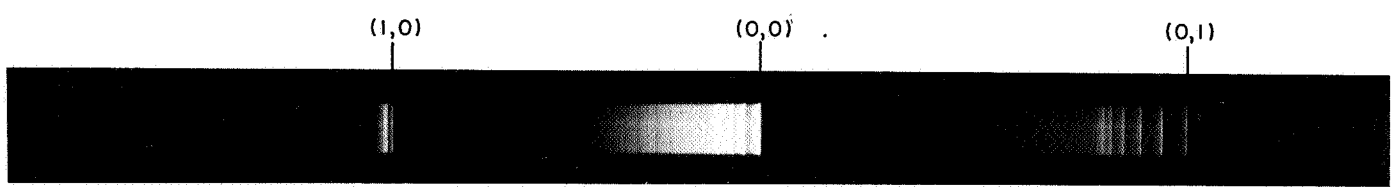

Fig. 10. Calibration spectrograph showing rotational structure of CN violet band system

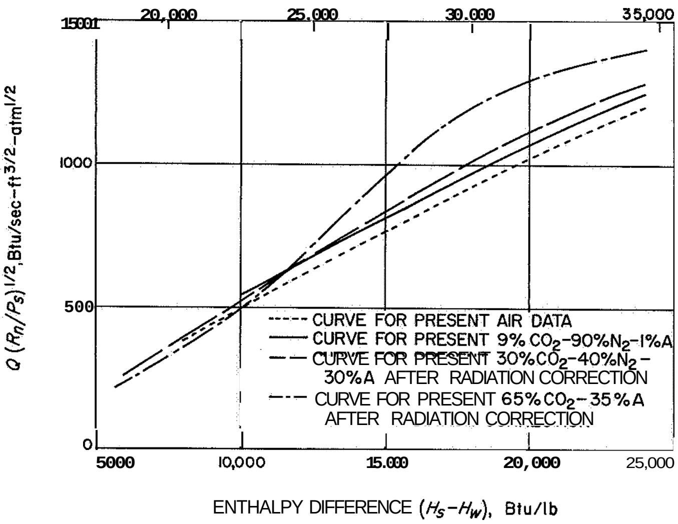

Fig. 12. Comparison of curves of stagnation-point heat-transfer data for various atmospheres

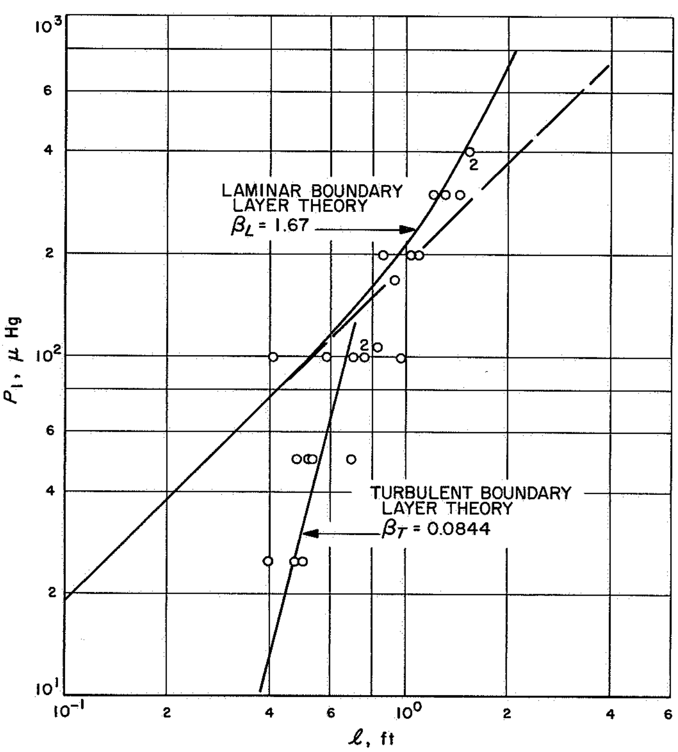

Fig. 13. Variation of length of test slug with initial air pressure

STUDY OF SOME TECHNIQUES AND LIMITATIONS OF ACOUSTIC NOISE SPECTRUM SHAPING

NASA Work Unit 124-07-02-01-55
JPL 324-70501-2-3740

C. D. Hayes

OBJECTIVE

The object of this task is to investigate possible ways of shaping the sound spectrum of high-intensity sound which could be applied toward better acoustic environmental testing.

The frequency response characteristics of an acoustic noise generating system is dependent upon the noise generator, acoustic horn (which is used as a coupler) and the region for which the noise is intended (such as a test chamber, progressive wave tube or "free space", etc.). Each of these elements has its own frequency response characteristics, and the frequency response characteristics of the entire system is a function of these separate characteristics.

At the present time there are development contracts under the Manned Spacecraft Center, Marshall Space Flight Center, Norair Division of Northrop Corporation, and W. A, D. C. to develop high intensity sound generators with broader frequency response characteristics. All of these development studies deal strictly with the sound generator itself.

This program is unique in that the sound generator itself will remain constant, and the sound spectrums will be studied under certain varying boundary conditions.

This program, as originally outlined, consists of three main areas of investigation:

1. Design of acoustic horns to obtain specialized response characteristics.
2. Study of the nonlinear effects of high intensity sound.
3. Spectrum shaping using absorber materials.

ACOUSTIC HORN DESIGN

Special acoustic horns have been designed and are presently being built. The design for these horns is based on acoustic horn theory for a special family of horns, which are referred to as "hyperbolic horns." These horns have the unique property—theoretically—of having a "resonant" response characteristic at frequencies just above their "cutoff" frequency.

We have performed a complete mathematical analysis for this type of horn, and we are presently performing a digital computer program to obtain frequency response data for several horns, which are presently being fabricated. A specially designed low-frequency generator has been built to verify the results of the above analysis. {A full report on this phase of the overall task is being written and will be completed upon verification of the analysis with our Laboratory experiments).

Close correlation between the theoretical and the experimental data for the above program will allow a design parameter analysis of horns, which have special response characteristics, and in our case, horns which have optimized resonance properties just above "cutoff." This analysis would be performed by a digital computer program before any actual fabrication begins.

NONLINEAR EFFECTS OF HIGH-INTENSITY SOUND

It has been predicted and verified experimentally that at very high-intensity levels the transmitting medium (air) responds to an acoustic signal nonlinearly. This results in the generation of harmonics. The addition of these harmonics to a broad-band acoustic spectrum can greatly alter the resulting acoustic spectrum. M. Lamers of JPL has written a report describing this phenomena and predicting the nature of the generated harmonics. Some preliminary experiments have been performed, using the JPL 2-in.-diameter high-intensity plane-wave acoustic tube, to demonstrate these effects. Extensive experiments are planned to accurately determine the role these nonlinear effects can have in shaping acoustic noise spectrums.

SPECTRUM SHAPING USING ABSORBER MATERIALS

When acoustic noise is confined in an enclosure, as in reverberant field or progressive wave test chambers, the acoustic absorbant properties of the surfaces of the enclosure greatly affect the resulting acoustic spectrums. Specially selected materials, which have particular absorbant properties (as a function of frequency), may be placed on these surfaces to produce a shaping effect on the resulting spectrums.

Preliminary studies have been performed at JPL to verify this technique. Materials, such as celotex, horsehair, polyurethene foam, spun glass insulation, etc., were used. These tests indicated that this technique can produce significant changes in the acoustic spectrums.

Further, more extensive work is planned which will "calibrate" usable materials for use in shaping acoustic noise spectrums.

It is also important that these spectrum shaping techniques be perfected before studies can be undertaken into the area of combined acoustics and vibration testing, since this application requires maximum control of the individual acoustics and vibration inputs.

20-INCH SUPERSONIC WIND TUNNEL
NASA Work Unit 124-07-04-01-55
JPL 324-70100-7-3730
E. A. Laumann

FACILITY OPERATIONS

Because of manpower limitations, the 20-in. supersonic wind tunnel continues to operate on approximately a half-time basis by sharing the crew with the 21-in. hypersonic wind tunnel. The tunnel operates over a range of Mach numbers from 1.2 to 5.0 with high-quality flow. Its variable density capability permits Reynolds number variations of a factor of 30. Through the use of auxiliary equipment numerous testing techniques are available for use in this facility. These include: force measurements, pressure measurements, temperature and heat transfer measurements, dynamic stability measurements, optical flow visualization, free flight, pressure telemetry and non-Earth atmospheres.

PLANETARY ENTRY STUDIES

The free-flight body-drogue studies were continued and are reported in Ref. 1. The effect of variation in forebody diameter ratio, and drogue diameter to forebody diameter were investigated. A JPL TM summarizing the results of this study to date is currently in the draft stage.

The experimental phase of the blunt-body planar dynamic stability program which included both free flight and free oscillation tests, was completed during the period. This consisted of a parametric study of the effects of Mach number, Reynolds number, center-of-rotation position, and oscillation amplitude on a family of 10-deg half-angle blunted cones. Comprehensive results of this program will be published during the next six-month period.

A report, Ref. 2, containing a complete description of the free-flight and free-oscillation techniques for wind tunnel dynamic stability testing has been completed and is in the process of being published. The report is intended as a basic guide for conducting a wind tunnel dynamic test program utilizing either technique,

An analytical study of the effect of atmospheric gusts on the stability of a ballistic vehicle on a Martian descent trajectory has begun. The effects are being compared through the use of the JPL 6-degree-of-freedom trajectory program which is being perturbed several ways to simulate gusts.

TESTING SUPPORT

Work in support of NASA Edwards on the extended performance version of the X-15 continued into the period of this report. This phase of the testing was completed.

A TRW Systems Division wake study in which pitot, static, and temperature surveys were taken across the wake of a series of wire-supported 10-deg half-angle blunted cones was completed in this period and the results summarized in Ref. 3. The program is Navy-sponsored.

A test in support of a CIT investigation of the effects of aspect ratio on two-dimensional supersonic flow separation was completed and reported in Ref. 4. The results of the test determined an aspect ratio limit for effectively two-dimensional flow. It also demonstrated that the effective aspect ratio could be varied by means of fins without introducing serious end effects.

TESTING TECHNIQUES

Evaluation of a mechanism to release two free-flight models from a single-wire suspension was conducted in the 20-in. supersonic tunnel. The high-speed film results show the technique to be quite promising, especially for tests of aft cover ejection. Two, 10 deg half-angle cones released into tandem flight are shown in Fig. 1, and an exploded view of the model construction and mechanism is shown in Fig. 2.

Experiments were conducted on splitting the schlieren light path into two beams intersecting at the free-flight region of the tunnel working section at 60 deg. This technique is proposed to permit high-speed filming of spinning free-flight models released at angles of attack up to 20 deg. Additional experiments are planned to evaluate actual free-flight models, camera, and film speeds required. Development of a technique for launching spinning models is planned for the period January to June 1966.

FACILITIES AND EQUIPMENT

The wind tunnel was shut down for a period of 9 weeks to permit the complete inspection and refurbishing of the compressor plant. The compressors and motors were disassembled and subjected to a thorough inspection. The rotors of two motors were reworked by Westinghouse. Much needed maintenance and updating of wind tunnel equipment was also executed during this time.

A calibration of the nozzle-flow was conducted to determine the pitot-pressure and the Mach number distribution in the test rhombus. This was done after the nozzle had been repositioned and aligned with the aid of template used specifically for this purpose. The nineteen calibrated Mach numbers, which range from 1.33 to 5.01, were checked at their maximum supply pressures. For some Mach numbers, adjustments were applied to the contour, in order to establish a Mach number variation less than ±0.01, on the tunnel centerline (in the test-region). The majority of contours compared favorably with the results of the last flow calibration which took place approximately three years ago.

A mockup of the new model support sector design has been tested to evaluate the effect upon diffuser performance. Results show that minor modifications to the design to accommodate high Mach and high angle of attack operation will be required.

The stable of six-component strain-gage balances have been improved and augmented with the purchase of two balances. One will replace an existing balance, which is still in use, but will not withstand any future repairs. The other augments the stable by providing a smaller diameter balance for nose cone studies or similar tasks.

In order to improve the quality of high-speed movies (4000-5000 frames/sec) taken during free-flight tests, a high-rate stroboscope light source was installed in place of the steady mercury vapor lamp typically used with the schlieren system. The new unit is syncronized with the high-speed camera. A significant improvement in film image resolution has been realized.

CONTRACTS

The contract (JPL A4-229415) with Telecomputing Services Inc. has been completed, The planar motion free-flight test series are virtually complete so that further film data reduction services are not required. When the biplanar free-flight testing technique becomes further developed, data reduction contract services will again be considered.

MEETINGS

The following is a list of the meetings attended in furtherance of the general task area:

1. AIAA 2nd West Coast Annual Meeting and Technical Display.
2. 24th Supersonic Tunnel Association Meeting.
3. ASSET/ Advanced Lifting Re-Entry Technology Symposium.

REFERENCES

1. Goranson, G. M., "Free-Flight Wind Tunnel Body-Drogue Studies," JPL SPS 37-35, Vol. IV, p. 83.

2. Prislin, R. H., <u>The Free Flight and Free Oscillation Technique for Wind Tunnel Dynamic Stability Testing</u>, JPL TR 32-878 (to be published).

3. Walker, B., "Cone Wake Study," JPL SPS 37-35, Vol. IV, p. 86.

4. Walker, B., "Aspect Ratio Effect," JPL SPS 37-35, Vol. IV, p. 84.

Fig. 1. Tandem models in free flight

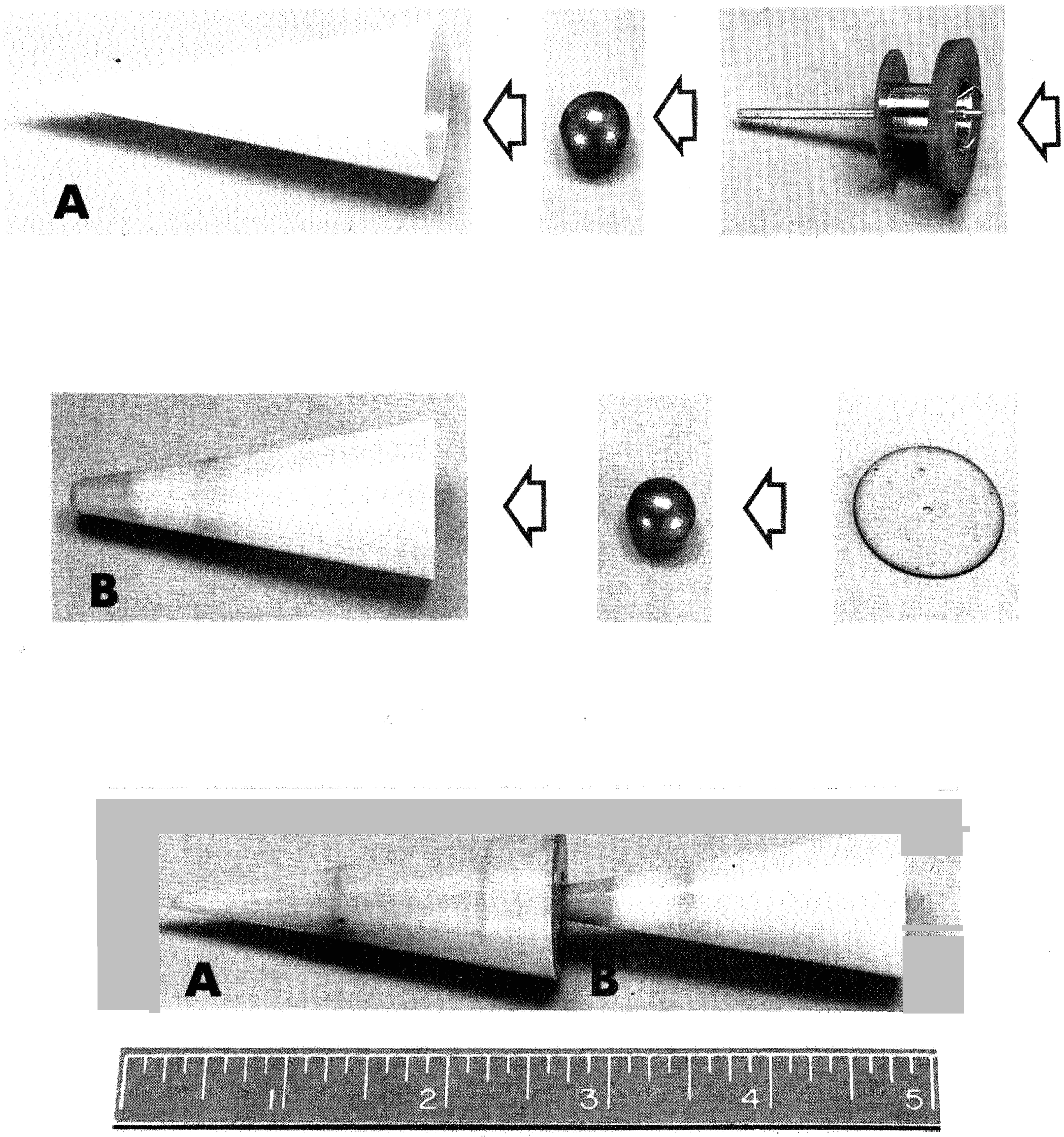

Fig. 2. Tandem model release and equipment

21-INCH HYPERSONIC WIND TUNNEL
NASA Work Unit 124-07-04-02-55
JPL 324-70400-2-3730
E. A. Laumann

FACILITY OPERATIONS

The 21-in. hypersonic wind tunnel continues to operate on approximately a half-time basis because of manpower limitations. Crew sharing with the 20-in. supersonic wind tunnel continues as a standard mode of operation. The tunnel operates over a range of Mach numbers from 4.0 to 11.0 with high-quality flow. Its variable density capability permits Reynolds number variation of a factor of 30. Through the use of auxiliary equipment numerous testing techniques are available for use in the facility. These include: force measurements, pressure measurements, temperature and heat transfer measurements, dynamic stability measurements, optical flow visualization, free flight, pressure telemetry, and non-Earth atmospheres.

PLANETARY ENTRY STUDIES

The static aerodynamic characteristics of a series of entry capsule afterbody shapes when combined with a blunted 60-deg cone forebody were obtained and reported in Ref. 1. The tests were conducted at a Mach number of 6.0 over at angles of attack up to 180 deg for a range of Reynolds number from 0.06×10^6 to 0.26×10^6.

A brief analytical comparison has been made of low L/D lifting entry with the ballistic case (L/D = 0) for the same shape using the six-degree-of-freedom entry program. Results have indicated that, for the conditions of the study, lifting entry at high entry angles is not practical even with large velocity changes prior to entry. Further, at low entry angles near the skipout limit where impact velocities are reduced to more practical values, the trajectories are critically dependent on the predicted atmosphere to the point that this type trajectory is also impractical. Therefore, the lifting entry does not appear to be competitive with the ballistic case at identical ballistic coefficients.

A third-order polynominal approximation to the equilibrium flow field about a blunt body is nearing completion and will be programmed for the IBM 7094 in the near future for use in connection with planetary entry studies.

A preliminary computer study has been completed to investigate the degree of accuracy to which an atmospheric density profile and a trajectory can be constructed as a function of the number, spacing, and accuracy of accelerometer measurements made during entry.

TESTING SUPPORT

A final report of the Saturn 1B/Saturn V cold-wall studies was completed in support of MSFC and a further test, using the JPL cold-wall model is currently under way.

TESTING TECHNIQUES

Modifications were made to the existing launch gun to enable flights with an angle-of-attack range from 0 to 20 deg. During the testing phase, test runs were made using all plastic models and it was found that because of the precooling and the short duration of the flights, the plastic withstood the high temperatures (1100° supply temperature) sufficiently to warrant their use as opposed to using thin-walled expensive metal models.

FACILITIES AND EQUIPMENT

A new variable speed drive system was incorporated into the model support sector of the tunnel. The modification will now permit the sector to be driven at any rate up to 5 deg/sec. This new capability will overcome some of the difficulties encountered previously with cold-wall testing.

An experimental study was made of a method for improving the schlieren image quality in the 21-in. hypersonic wind tunnel. Uneven heating of the quartz schlieren windows produced an uneven darkening of the image (see Fig. 1). A previous attempt to cool the window surface resulted in a moderate improvement in the schlieren-image quality. However, removal of the windows eliminated the uneven darkening altogether. Tunnel performance was not adversely affected and schlieren photographs can be taken at conditions previously not possible.

A facility was designed and built primarily to conduct experiments and tests that could not be accommodated in the supersonic or hypersonic wind tunnels (see Fig. 2). This auxiliary flow channel, as it is called, is versatile, requires minimum maintenance, and utilizes the existing wind tunnel compressor plant and associated equipment. A series of cold-flow rocket nozzle tests have already been conducted. In addition, a wide variety of additional experiments can be handled in this type of facility, some of these may be (1) pressure distribution and heat-transfer measurements on nozzles, (2) laminar-turbulent boundary layer studies, (3) aerodynamic measurements on model magnetically supported, (4) multi-gas operation, (5) free-flight model testing, and (6) high Reynolds number testing and a Mach number 15 condensation-free capability.

A rapid scanning pressure system capable of recording 120 pressures in a minimum of 3 sec was designed at the Laboratory. The pressure measuring system consists of ten scanner units of 12 port each. One transducer is mounted in each scanner. Utilizing this concept, a transducer can be designated to record the pressures that it can most accurately handle. This equipment is being used not only for wind tunnel testing but also for propulsion work.

MEETINGS

The following is a list of the meetings attended in furtherance of the general task area:

1. AIAA 2nd West Coast Annual Meeting and Technical Display.
2. 24th Supersonic Tunnel Association Meeting.
3. ASSET/Advanced Lifting Re-Entry Technology Symposium.

REFERENCE

1. Marko, W., "Entry Capsule Afterbody Configuration Study," JPL SPS 37-35, Vol. IV, p. 77.

OTHER REPORTS

The following reports relate to previous works that have been published since July 1, 1965:

1. Koester, H. and Fox, N., The Use of Conventional Wind Tunnels to Simulate Planetary Atmosphere Aerodynamics, JPL TR 32-762, November 15, 1965.

2. Welton, J., Free-Flight Telemetry Testing in the JPL Wind Tunnels, JPL TR 32-275, September 15, 1965.

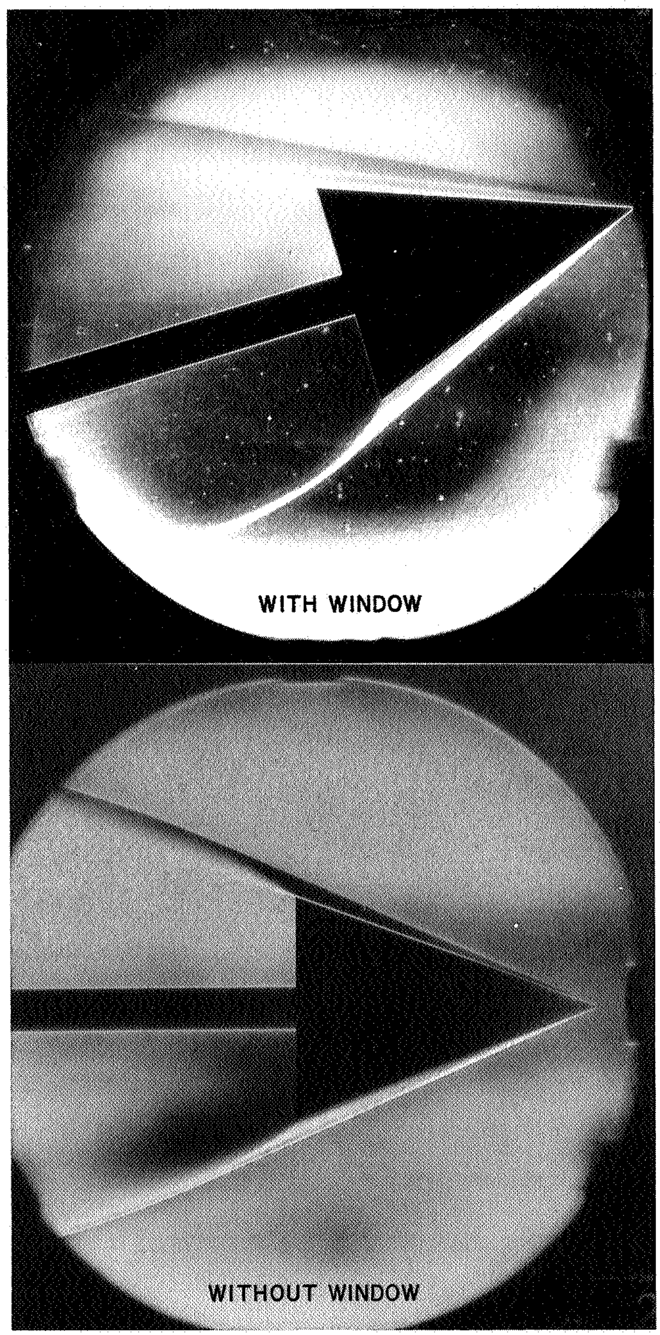

Fig. 1. Schlieren photograph comparisons

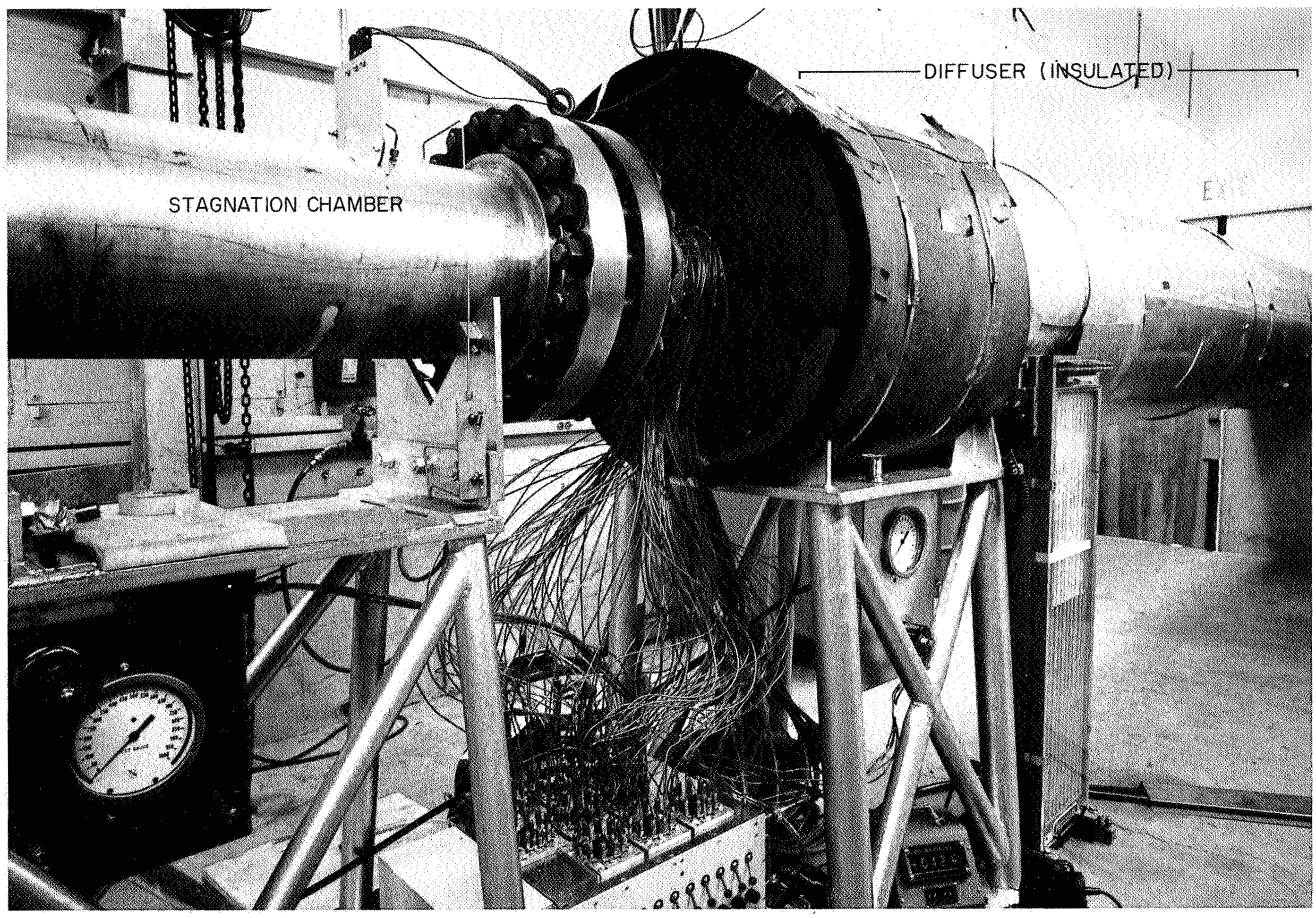

Fig. 2. Auxiliary flow channel

SPACECRAFT STRUCTURES (124-08)

PLANETARY ENTRY HEAT SHIELDS
NASA Work Unit 124-08-03-02-55
JPL-324-80401-2-3510

Robert G. Nagler

OBJECTIVE

Because of an interest in future planetary-entry missions under the Voyager Project, JPL must continue to maintain and improve its engineering understanding of heat-shield materials and materials analysis, New Martian environments, materials and materials concepts, test data, analysis tools, and fabrication techniques must be integrated into the JPL system to allow use of the latest methods and inputs for future mission studies, vendor selection, predesign studies, and final capsule design. The objective for FY 1966 is to establish the basis for a satisfactory understanding of the heat-shield requirements during Martian entry for future Voyager missions.

COMPUTER ANALYSIS

Calculations were made of the heat-shield weight distributions necessary to protect several typical Mars entry vehicle configurations during a wide variety of possible Mars entry environments. Apollo and sphere-cone configurations were investigated as to the effect of size, center-of-gravity location, and ballistic coefficient on heat-shield weight estimates. Entry velocity, entry angle, and initial entry angle of attack were varied, and recent JPL design atmospheres including the Mariner-IV Mars occultation results have been used. Equilibrium stagnation point convective and radiative heat pulses are used which include some allowance for grey gas absorption in the thick shock layers of large bodies.

Time-temperature and weight loss calculations have been made on the following materials:

1. Methylphenyl silicones reinforced with aluminum silicate.
2. Phenolic resin and phenolic microballoons reinforced with nylon powder.
3. Epoxy resin and phenolic microballoons reinforced with silica fibers.

A first draft is nearly complete, summarizing the findings in this parametric study. The report is entitled "The Variation in Heat Shield Weight Requirements for a Matrix of Possible Martian Entry Environments and for Compatible Mission-Related Design Constraints."

The method of obtaining heat-shield weight estimates developed in this report will provide realistic upper limits for any set of trajectory parameters and may be used with some confidence during initial planning. Estimated values may be read directly off graphs to fit any combination of inputs for ballistic entry into Mars. A sample of the final results for two more or less extreme cases of entry conditions and design constraints is shown in Fig. 1.

Additional ablation computer programs are in the process of being acquired from Ames Research Center, Langley Research Center, and Manned Spaceflight Center to update JPL's present capability. No action has been taken on the computer roundrobin effort due to lack of suitable manpower.

MATERIALS PROPERTIES FOR COMPUTER INPUTS

The contract[1] with Arthur D. Little, Inc. to determine the reflectance of phenolic nylon chars as a function of temperature, wave length, angle of incidence, and surface roughness has been completed, and the final report is in production. The final report will be entitled "Measured Directional Reflectances of Chars in the UV, Visible and Near Infrared." No difference was found in the reflectance of two chars with widely different surface roughness. Reflectance was both spectral and diffuse. Temperature did not seem to affect the reflectance significantly unless enough oxygen was present to drastically change the surface.

PLASMA-GENERATOR FACILITY

Changes in the Laboratory made it necessary to relocate the plasma-generator facility. It has now been given a permament home in the new Materials Laboratory Building. The engineering on the new facility location is in process and the move should be complete by the end of this fiscal year.

A new power supply is being purchased which can be pulsed in simulation of real trajectories (the Mars entry environment is the first one capable of full simulation, except geometry, in this way). The RFP for the new power supply has been issued; a bidders' conference has been held, and the bids are due in January.

Avco RAD, Plasmadyne, Electro-optical Systems, Ames Research Center, Langley Research Center, and the Manned Spaceflight Center have been visited to determine the type of radiant heater system suitable for Mars entry simulation, and a RFP is in process. The engineering has also been started on the gas system.

A close working arrangement has been established formally and informally with Ames Research Center, Langley Research Center, and the Manned Spaceflight Center to ensure rapid dissemination of information and avoid unnecessary duplication. Ames and Langley are also running several test programs in support of future _Voyager_ needs. These test programs were developed jointly by JPL, Ames, and Langley to fit into the overall _Voyager_ picture.

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[1] JPL Contract 905867 – "Study Program to Develop and Analyze Techniques for the Measurement of High Temperature Spectral Emissivities and Reflectivities of Specified Materials," A. D. Little, Cambridge, Massachusetts, $35, 000 (FY 1964 AD Funds) initiated Aug. 1964, final report Nov. 1965.

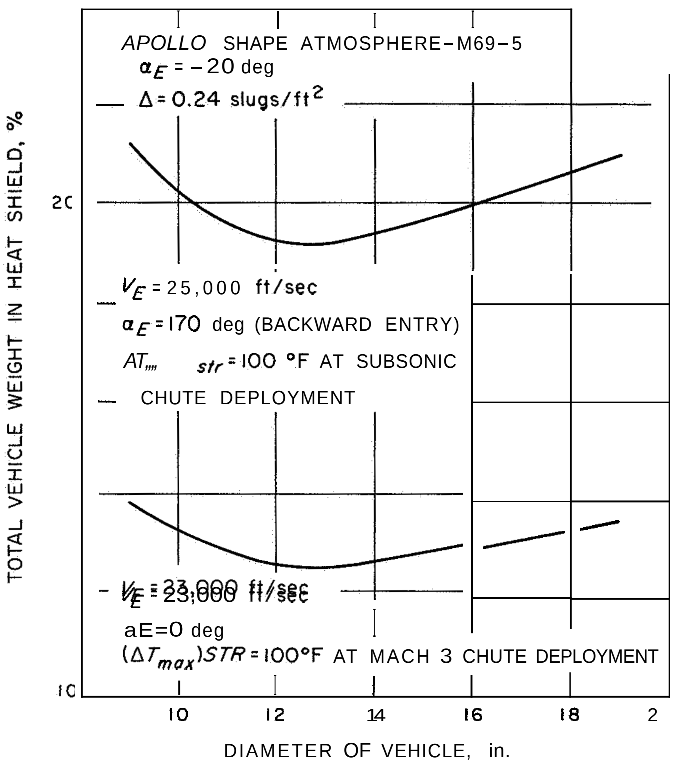


Fig. 1. Effect of body size on heat shield weight requirements

ENTRY DYNAMICS

NASA Work Unit 124-08-05-01 (FY 1965)
JPL 324-80501-2-3530 (FY 1965)

J. Spiegel

Negotiations are in process, following the award of a contract to the General Electric Company, Re-Entry Systems Department. Personnel at the NASA Ames Research Center were very helpful in evaluating the three proposals received from this solicitation.

This study is directed toward the identification of potential aerothermoelastic problems of very lightly loaded entry vehicles and the solutions to these problems. The study will include the following areas:

1. Flutter.
2. Buffeting.
3. Effects of elevated material temperatures and temperature gradients on 1 and 2.
4. Forced vibration.
5. Acoustics.
6. Static Aeroelasticity.

SPACECRAFT SHELL STRUCTURES
NASA Work Unit 124-08-06-03-55
JPL 324-80101-2-3530
T. E. Lang

OBJECTIVE

To study, in general, the static and dynamic properties of shell-type structures. Knowledge gained is to be applied to the analysis of shell structures likely to be used in lunar and planetary entry capsules. Closed-form solutions of the simpler shell configurations are used to establish an intuitive understanding of shell characteristics (small and large deflection) to symmetric and asymmetric atmospheric pressure, local attachment, and thermal loadings. Emphasis is placed on development of the numerical techniques of the finite element method to analyze the more general shell-loading cases and nonhomogeneous shell constructions. Results of this effort reflected in automatic computer programs and analytic solutions are summarized in a form suitable for general distribution and use.

STRUCTURAL ANALYSIS AND MATRIX INTERPRETIVE SYSTEM (SAMIS) COMPUTER PROGRAM

The abbreviated callout of the computer program has been changed from SAS to SAMIS to more accurately define the functions of the program. Previously it was not evident from the title of the program that a matrix manipulative capability was an integral part of the program function.

Work of the computer program in follow on tasks by the contractor (Philco Corporation, Western Development Laboratories, Palo Alto, California) was delayed approximately two months due to unavoidable circumstances. However, progress was made on the DEQS subprogram (Differential Equation Solver for arbitrary time-vary-varying forcing functions), which is now in final checkout; on the ADDS subprogram (addition of two or more matrices) to reduce its operating time; and modifications and additions to the BILD subprogram {generation of stiffness, stress and mass matrices) as per contractual phase Ia requirements.

As far as the stress computation in structures approximated by triangular elements is concerned, the nodal force averaging technique for computing moments and transverse shears has been abandoned due to unjustified arbitrariness involved in establishing a distribution technique. Instead, for these stresses, a simple transverse deflection distribution in the element is defined by means of the nodal rotations and transverse deflections of this element. The curvatures and the rate of change of curvatures of this distribution are then used in the computation of moments and transverse shears of the associated element. Moments thus obtained are very satisfactory even for few element approximations. However, the transverse shears calculated with this method are not quantitatively accurate although they reflect the true variation. This procedure preserves the modular character of the calculate, i. e., stresses in a triangle are computed from information taken only from the same triangle.

A least-squares scheme is also under development for evaluating moments and transverse shears, which, however, does not retain the modular character.

Results to date indicate that the particular least-squares scheme being used yields considerably more accurate moments and transverse shears than the above-mentioned modular scheme.

With the possibility of a large distribution of the computer program, as well as the program reports, modifying and updating of the contractor's Technical and Programmers documents was initiated. The scope of material included in the reports was established to be compatible with a mutually agreed upon version of the computer program that will be distributed with the reports. Unfortunately, due to manpower constraints, no progress can be reported on writeup by JPL of a User's document which will contain a detailed description of the test problems solved in checkout of the program. The absence of information that will be included in this document is currently holding up distribution of the computer program.

The contractor work on SAMIS will continue with phases Ia and II of the program. JPL effort will be centered on completion of the User's document, so that a version of the computer program can be distributed upon request.

Professor H. Martin of the University of Washington has successfully determined a simple derivation of the stiffness matrix for a triangular element. The derivation is amenable to representation of orthotropic materials which is in process of being introduced in this model. Professor Martin is also updating a report written for the Laboratory originally in 1963 on the subject of large deflection of structures with application to the finite element method. This report should be published in the fourth quarter of FY 1966 as a JPL TR.

In addition to the work by Professor Martin, several areas of development are presently under investigation by JPL personnel with regard to the triangular element. One modification under study is addition of curvature to the element representation to improve displacement continuity. A second study centers on improving mass lumping techniques to increase the accuracy of dynamic calculations for a given grid arrangement. These topics coupled with Professor Martin's work are being considered for input into a comprehensive document treating the triangular element in detail.

CLASSICAL SOLUTIONS OF SHELL PROBLEMS

This support function of developing analysis capability relating to capsule structure problems has resulted in one report with three additional reports in process. The released report is entitled An Evaluation of the Effect of Finite Shear Strain in a Shallow Spherical Shell, JPL TR 32-780, October 1, 1965.

Reports in process are on the subjects of thermal stress in shallow spherical shells of sandwich construction, and evaluation of transverse shear stress in a square clamped plate.

This general effort is expected to be expanded into the subject of large deflection of shell-type structures in the near future.

SPACE VEHICLE ENVIRONMENTAL FACTORS (124-09)

HIGH VACUUM RESEARCH – MOLSINK

NASA Work Unit 124-09-04-01-55
JPL 324-90301-2-3750
R. E. Bartera

OBJECTIVE

The long-range objective of this work unit is to improve the fidelity of simulation of interplanetary space. The immediate goal is to develop the technology of simulation of the space molecular sink to the point where it may be a useful tool for evaluation of spacecraft configuration and components.

THE 18-in (MOD. I) MOLSINK

A relatively crude molecular sink simulation chamber (MOLSINK) had been previously constructed. It operates in the 10^{-10} torr "pressure" range obtained with sorption, titanium sublimation, and ion pumps and has an 80°K molecular trap shroud (MOLTRAP).

The strong effect of the Mod. I MOLSINK on spacecraft hardware was demonstrated quite strikingly and a complete report of that experiment appears in JPL SPS 37-36, Vol. II. The results influenced the Mariner IV Mars encounter sequence.

An experiment to determine the effect of MOLSINK on bacterial spores is now in progress in conjunction with an evaluation of long-term, continuous operation characteristics of the MOLSINK components. A report will be published at the completion of the experiment in about six months.

An investigation of the possibility of titanium (from the sublimation pump) migrating to a test item was completed. There appears to be no problem, but the experiment will be repeated in the Mod. II MOLSINK (see below) when it is completed.

CRYSTAL MICROBALANCE

We have continued to improve our ability to use quartz crystal microbalances (cf. JPL SPS 37-34, Vol. IV). A sensitivity of 10^{-10} gm/sq cm is easily achievable; less than the mass of a layer of water one molecule thick! We are now investigating its use to monitor deposition rate and pumping speed of titanium with time. This is required to accomplish the economical use of titanium necessary for the long time, continuous pumping characteristic of MOLSINK tests.

THE 10-ft (MOD. II) MOLSINK

A brief but comprehensive description of this facility research tool has been written and will be published in a forthcoming issue of the AIAA journal of Spacecraft and Rockets; JPL TR 32-901 gives further information on this subject. The design and fabrication of the Mod. II MOLSINK has progressed satisfactorily considering the resources assigned to it: The chamber support structure, hydraulic hoist system, and rough vacuum pumping systems have been installed; developmental work on the MOLTRAP shroud was completed and fabrication has started; a contract was let to fabricate the outer and inner vacuum vessel shells. We now expect to have a working system with an 80°K MOLTRAP about August, 1966.

To effectively trap the common molecules of N_2, O_2, CO, CO_2, and A, the MOLTRAP should be at about 20°K. Early in the reporting period, quotations were solicited from several vendors for mechanical refrigeration systems to provide this temperature, The quoted prices were far in excess of available funds. Efforts to obtain permission to establish a 5400-gal liquid hydrogen storage facility (so that a low capital investment, open-cycle hydrogen cooling systern could be employed) were not successful. An attempt is now being made to secure adequate funding for the mechanical refrigeration approach. Delivery of such a refrigerator is about nine months.

EFFECT OF ENVIRONMENT ON SPACECRAFT THERMAL CONTROL MATERIALS

NASA Work Unit 124-09-05-01-55
JPL 324-90401-2-3510

W. M. Hall

OBJECTIVE

The objective of this work unit is to establish the reasons for the observed stability of zinc oxide pigmented coating systems. This is to be accomplished by identifying and determining the properties of the energy-absorbing centers in zinc oxide and by studying the effect of selected impurities on the optical absorption of this material.

PROGRESS TO DATE

The work has been performed by Illinois Institute of Technology Research Institute under JPL Contract 950746, and has consisted of an evaluation of the published technical literature on zinc oxide photolysis and of selected experiments to establish the nature of the photolysis effect.

Evaluation of published reports on the effects of mechanical, thermal, and irradiation treatments on the optical properties has aided in the interpretation of the results of the experimental program. In these reports electron spin resonance has been used to identify species formed as a result of various treatments.

The experimental work has been done in three categories. (1) Reflectance changes due to mechanical and thermal treatment. Zinc oxide powder specimens were heated in air and in a mixture of hydrogen and argon to temperatures within the range of 1000 to 1800°F for varying periods of time. Other powder specimens were ball-milled (without heating) for a length of time sufficient to yellow the zinc oxide. The change in spectral reflectance resulting from these treatments essentially confirmed the data reported by others. These data show a depression of the reflectance in the spectral region of the absorption edge for natural zinc oxide. The ratio of spectral reflectance of untreated to treated zinc oxide goes through a sharp peak at 0.37 to 0.38μ, with the peak amplitude varying directly with the severity of the thermal or mechanical treatment. It is postulated that an interstitial zinc defect is formed which gives rise to the observed change.

(2) Luminescence effects of mechanical and thermal treatment. These experiments were intended to determine the relationship, if any, between the absorption changes and the luminescence spectrum. Zinc oxide powder specimens were heated to 1400°F in air and in a mixture of hydrogen and argon, and other powder specimens were ball-milled as before, Luminescence spectra of these treated specimens of untreated zinc oxide and of lithium doped zinc oxide were determined and compared. The specimen heated in air showed a large increase in luminescence in the 0.6 micron region. The specimen heated in the mixture of hydrogen and argon showed little change. The lithium doped specimen showed a decreasing luminescence in the 0.6μ region with increasing lithium content, The interpretation placed on these experimental results is that the interstitial zinc defect is not involved with the weaker 0.46 - 0.50μ region of luminescence.

(3) Effects of atmospheric environment. Recent results indicate that the reflectance of zinc oxide in the near-infrared region is severely degraded when the ultraviolet irradiation is performed in vacuum, however the degradation is recovered when the sample is exposed to air. Lithium doped zinc oxide exhibited this same behavior but to a much lesser degree.

TEMPERATURE CONTROL OF LARGE SPACECRAFT
NASA Work Unit 124-09-05-02-55
JPL 324-90501-2-3530
J. W. Lucas

OBJECTIVE

The long-range objective for this work unit is to develop advanced test techniques and active thermal control devices for the future relatively large unmanned spacecraft. For the current year the objectives are (1) to complete the out-of-house contract on detailed scale modeling of the Mariner IV spacecraft, (2) to carry out in-house testing and modification of the scale model of Mariner IV, (3) to complete an out-of-house contract to prepare a handbook for steady-state thermal modeling, (4) to monitor a NASA Headquarters research grant on transient modeling, and (5) to renew research on active devices.

THERMAL SCALE MODELING

The contract on thermal scale modeling in steady state conditions, at 0.43 scale, of Mariner IV spacecraft was completed by Arthur D. Little, Inc., (ADL). This contract was initiated in FY 1964 with NASA/JPL Contract 950789 under NASA Work Unit 124-09-05-02 and JPL 324-00905-2-3540. The total funds for the entire contract remained at $189, 708. The final portion of the contract was phase III, in which significant external appendages were added to the basic octagon and the model was tested at Lewis Research Center in a cold-wall, vacuum chamber with solar simulation over the octagon. A photograph of the prototype and the model together is shown in Fig. 1. The major contractor effort during the report period was the preparation and submission of the final written report. The ADL project director F. Gabron visited JPL on July 29, 1965 and gave his oral report. A number of engineers from NASA centers were in attendance in addition to JPL engineers. The final written report covering the entire contract effort is titled "Thermal Scale Modeling of the Mariner IV Spacecraft" and is dated August 20, 1965. The report was distributed to NASA Headquarters and NASA Centers, and to industrial firms and universities known to be interested in thermal modeling. A paper based on phase III of the contract and titled "Thermal Scale Modeling of the Mariner IV Spacecraft" by F. Gabron and R. W. Johnson of ADL and J. M. F. Vickers and J. W. Lucas of JPL was prepared in this period and accepted for presentation on January 24, 1966 at the AIAA 3rd Aerospace Sciences Meeting in New York. In addition, Dr. Vickers prepared a summary of phase III of the contract; it is titled "Thermal Scale Modeling" and appeared in JPL SPS No. 37-34, Vol. IV, August 31, 1965, pp. 88-91.

An oral presentation on thermal scale modeling was made by Dr. Vickers on November 17, 1965 to the Los Angeles Section of the ASME (Heat Transfer Division).

ADL shipped the scale model to JPL and it was received with no shipment damage in July 1965. ADL also sent all detailed information such as thermistor calibration needed for testing the model. Instrumentation for carrying out testing was prepared at JPL and the model was checked out ready for testing. Testing in the new JPL 10-ft space simulator was not carried out because of unavailability of the simulator; also, the JPL 25-ft space simulator was unavailable because of modification of the solar simulation beam. Current plans call for testing in February 1966 after Surveyor TCM (thermal control model) tests are completed in the 10-ft space simulator.

One of the Hy-Cal radiometers used in the Lewis Research Center tests has been loaned to JPL for use during the tests in the simulator together with the radiometers normally used. The three tests that were performed previously at Lewis Research Center will be repeated plus one additional with the beam at approximately one Earth solar constant. The scale model will then be redesigned and retested in-house. Dr. C.A. Rhodes is responsible for this effort which will also include fabrication, test, and analysis of models which exhibit key problem and/or possible exploitation areas.

Preparation of a handbook for steady-state thermal modeling was initiated December, 1965 with NASA/JPL Contract No. 951417 in the amount of $16, 835, $15, 000 of which was from FY 1965 funds. Arthur D, Little, Inc. was awarded the contract which is to be completed in April 1966, and F. Gabron is the project director. The handbook will be for use by project offices and project temperature control engineers and will treat temperature and materials preservation of unmanned spacecraft larger than Mariner IV and including an entry capsule for subsequent planet atmosphere entry.

Technical monitoring was begun of basic work on transient scale modeling by Professor B. T. Chao at the University of Illinois under NASA Headquarters Research Grant NGR 14-005-048 dated September 1, 1965. Activity during the report period was largely devoted to procurement of a cold-wall vacuum chamber. Requests for quotes were sent to several firms and final selection of the vendor was underway in December. Some theoretical analysis of modeling problems was initiated. Dr. J.M.F. Vickers, the monitor, plans to visit Professor Chao in January 1966 to determine what information is needed in addition to that presently being supplied. It is planned that the effort will be continued by means of a contract in the amount of approximately $50, 000.

ACTIVE DEVICES

Experimental tests of an improved capillary heat pipe design were initiated late in the report period to allow assessment of further work needed in this area.

During the summer Professor M. Suo of Massachusetts Institute of Technology carried out, at JPL, an approximate study of the relative importance of convective and radiative heat transfer inside a spacecraft lander on the surface of Mars. This study is being published as JPL internal document. In addition, a summary entitled "A Study of Convective Heat Transfer Within a Lander on Mars," was published in JPL SPS 37-35, Vol. IV, October 31, 1965, pp. 69-71.

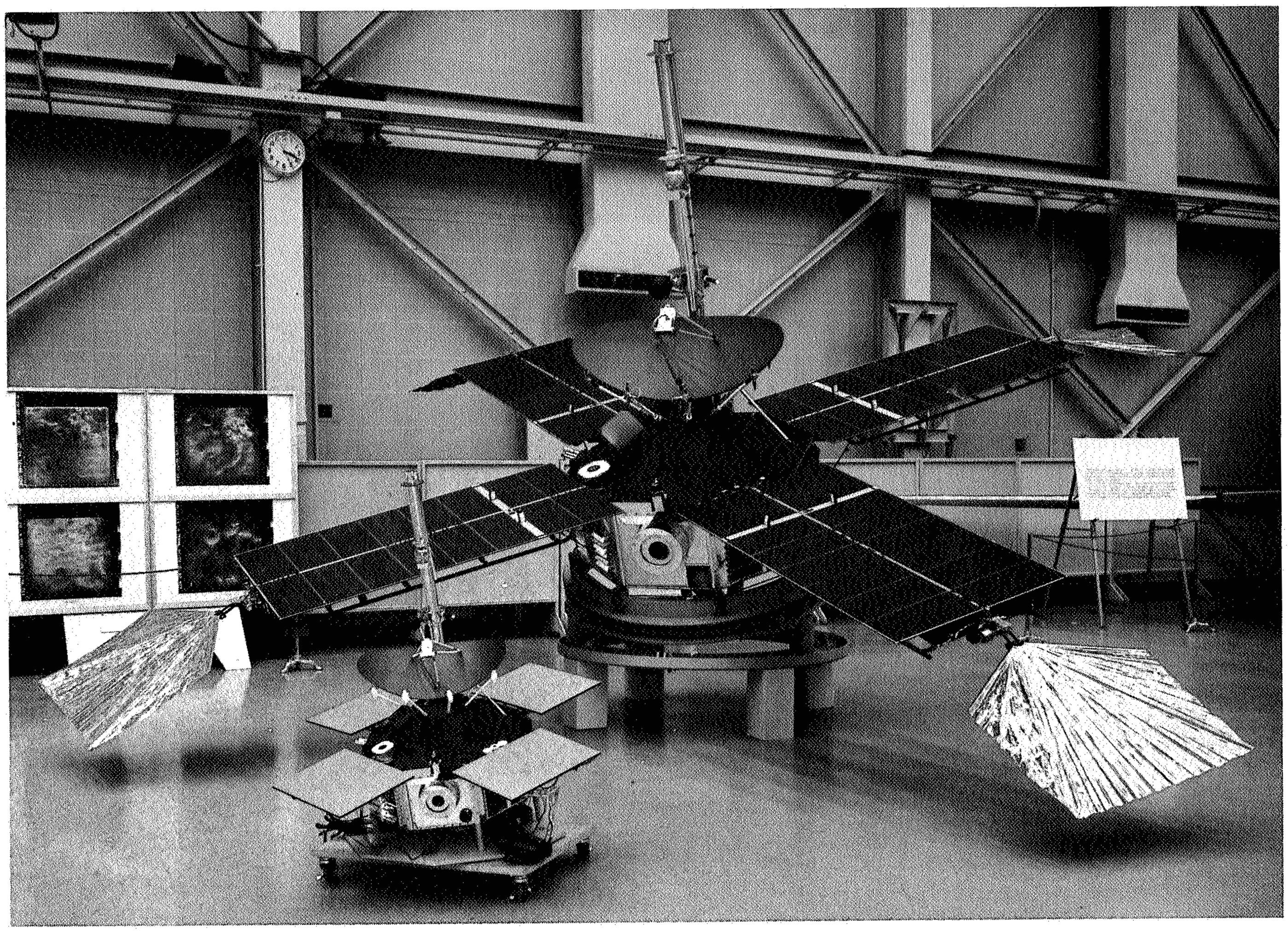


Fig. 1. Full-scale and half-scale Mariner Mars 1964 models

CONDUCTION AND RADIATION IN SPACECRAFT TEMPERATURE CONTROL

NASA Work Unit 124-09-05-03-55

JPL 324-90601-2-3530

J. W. Lucas

OBJECTIVE

The long-range objective for this work unit is to develop advanced analytical design, and test techniques which will allow prediction of conduction-radiation coupled heat transfer in spacecraft, For the current year the objectives are to (1) improve existing computer programs and determine the feasibility and method of formulation of a thermal analysis system, (2) determine some of the real-surface radiation heat transfer effects which are significant sources of error in analysis, (3) extend understanding of heat flow in joints to simplified bolt-like joints, (4) initiate analysis of the effects of imperfect collimation of solar simulation beams, and (5) initiate development of a miniaturized absolute cavity radiometer (MACRAD).

COMPUTER PROGRAMS

Comparison of the Nodal and Zone (conduction/radiation) computer programs was made by Dr. J. Hultberg for a common problem. It was demonstrated that (1) the Zone program conveniently solves problems expressed in terms of nodes as well as zones, (2) the same temperatures are obtained from each program, and (3) the Zone program indicates errors in input information, whereas the Nodal program does not. To illustrate further the use of the Zone program, several simple examples were solved with the zone or node method of mathematical model description. In addition, the improved CONFAC II form factor program was obtained.

An investigation of the problems involved in formulating an equation-writing program was initiated. A summary of this preliminary work was prepared for JPL SPS 37-36, Vol. IV, December 1965; it is by Dr. Hultberg and is titled "A Basic Thermal Analysis System Utilizing Computers."

During the next period it is planned to modify the Zone program to handle temperature dependent emissivity. Work on a thermal analysis system will also be continued.

REAL SURFACE EFFECTS

Analytical and experimental heat transfer studies to isolate, assess the magnitude of, and determine means for eliminating the substantial discrepancies which often occur between test results and analytical predictions were continued. These studies were of real-surface radiation effects which are ignored in engineering calculations at present, but are regarded as primary sources of errors.

1. Programming of a detailed radiation-conduction coupled analysis, based upon the diffuse idealization for a simplified version of the Ranger TV tower, was completed and numerical results were obtained using an IBM 7094 computer. During the next period an analysis based on the specular idealization will be undertaken.

2. Experimental correlation of the above analytical work did not progress as anticipated. This was primarily due to delays encountered in the procurement of a small laboratory solar simulator, and also because the development of the ACRAD (absolute cavity radiometer) required far more effort than originally anticipated. Delivery of the laboratory simulator is expected in January, 1966. Calibration of the entire facility will be carried out early in the next period; the experimental correlations will then be begun.

3. A paper has been prepared describing the formulation of a completely general analytical technique for obtaining view factors to images formed in nonplanar, specular surfaces. This paper entitled "On the Determination of View Factors to Images in Nonplanar, Specular Surfaces," by J. A. Plamondon and T. E. Horton of JPL, will be available early in 1966 as a JPL report.

4. Analytical work on nongray effects and polarization effects progressed satisfactorily. Solutions for radiant heat transfer in a nongray channel and a nongray wedge were obtained. A paper entitled "Radiant Heat Transfer from Nongray Surfaces with External Radiation" by J. A. Plamondon and C. S. Landram was prepared and accepted for presentation at the AIAA 3rd Aerospace Sciences Meeting on January 24, 1966. Solutions were obtained for polarization effects in a 90-deg wedge with dielectric surfaces. Formulation and numerical evaluation for metallic surfaces will be completed during the next period.

5. Technical monitoring was begun of basic work on real-surface effects by Professor R. G. Hering at the University of Illinois under NASA Headquarters Research Grant NGR 14-005-048. An assessment of the literature was made and preliminary numerical results for a wedge were obtained which will be reported in the next semiannual report. It is planned that the effort will be continued by means of a contract in the amount of approximately $25, 000.

THERMAL JOINT CONDUCTANCE

The JPL thermal joint conductance apparatus remains vacuum tight after addition of several handholes to greatly ease test setup operations. The existing automatic controls have been completely checked out for a continuous sample. Calibration of the apparatus by measuring the conductivity of ARMCO iron was initiated. During the ARMCO test it was learned that the thermocouple zone-box within the vacuum chamber is not a satisfactory approach; this was subsequently verified with NBS, Washington. The zone box was being replaced and other improvements were being made simultaneously at the end of the report period, The ARMCO iron calibration test will be carried out and followed with cut-bar tests,

Technical monitoring was performed of basic work on thermal joint conductance by Professor A. M. Clausing at the University of Illinois under NASA Research Grant NsG 242, Supplement No. 2. Preliminary results on two-dimensional and transient joint conductance will be reported in a semiannual report in

January 1966. In addition, Dr. Clausing prepared and submitted a paper titled "Heat Transfer at the Interface of Dissimilar Metals – The Influence of Thermal Strain" to the International Journal of Heat Transfer; this paper has been accepted for publication.

Technical monitoring was carried out on basic work on thermal joint conductance by Professor H. Fenech at the Massachusetts Institute of Technology under NASA Research Grant NGR 22-009-065. A theoretical and experimental analysis including roughness superimposed on waviness was begun. A paper entitled "Thermal Contact Conductance in a Vacuum Environment," by M. Yovanovich and H. Fenech was prepared and accepted for presentation at the AIAA 3rd Aerospace Sciences Meeting on January 24, 1966 in New York. A detailed report will also be prepared, It is planned to continue this effort with a contract in the amount of approximately $25, 000.

COLLIMATION EFFECTS

An RFP was sent out twice in order to generate competition for a contract to analytically determine thermal flux densities from various types of simulated suns, including a range of decollimation or field angles, on various geometrical forms. At the end of the report period it was expected that a contract would be let in January 1966 for $22, 000 in FY 1965 funds, The contract will be monitored during the next period.

ABSOLUTE CAVITY RADIOMETER

A greater than anticipated effort was required in the development of the absolute cavity radiometer (ACRAD), Difficulties in measurement accuracy were encountered which required a redesign of the instrument, and a significant improvement in accuracy of power measurement. The redesign resulted in what was considered a final prototype. A photograph and circuit diagram of the prototype are shown in Fig. 1 and 2, respectively. Measurement accuracies of 1% were obtained. Programming of an analysis was initiated to assess theoretical accuracy limitations, Planning was started for contracting the miniaturization of the prototype to make it more useful for research and to establish a supply of radiometers for others. During the next period testing of ACRAD in collimated irradiation will be carried out. Also, a contract in the amount of $70, 000 will be let during the latter part of the period for development of a miniaturized-ACRAD or MACRAD.

Two papers were prepared and published describing the radiometer; one paper is to be published in the ISA Transactions which is entitled "Cavity-Type Absolute Total Radiation Radiometers," by J. M. Kendall, Sr., F. Haley, and J. A. Plamondon; the other was published in JPL SPS 37-35, Vol. IV, October 31, pp. 66-69 entitled "Cavity-Type Absolute Total Radiation Radiometer," by J. A. Plamondon and J. M. Kendall, Sr.

In the midyear budget review, it is planned that the ACRAD/MACRAD effort will be assigned to a new NASA Work Unit 124-09-05-05.

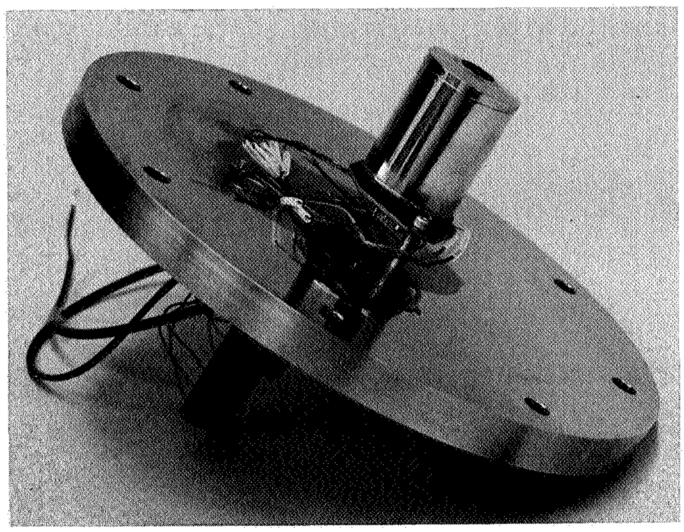
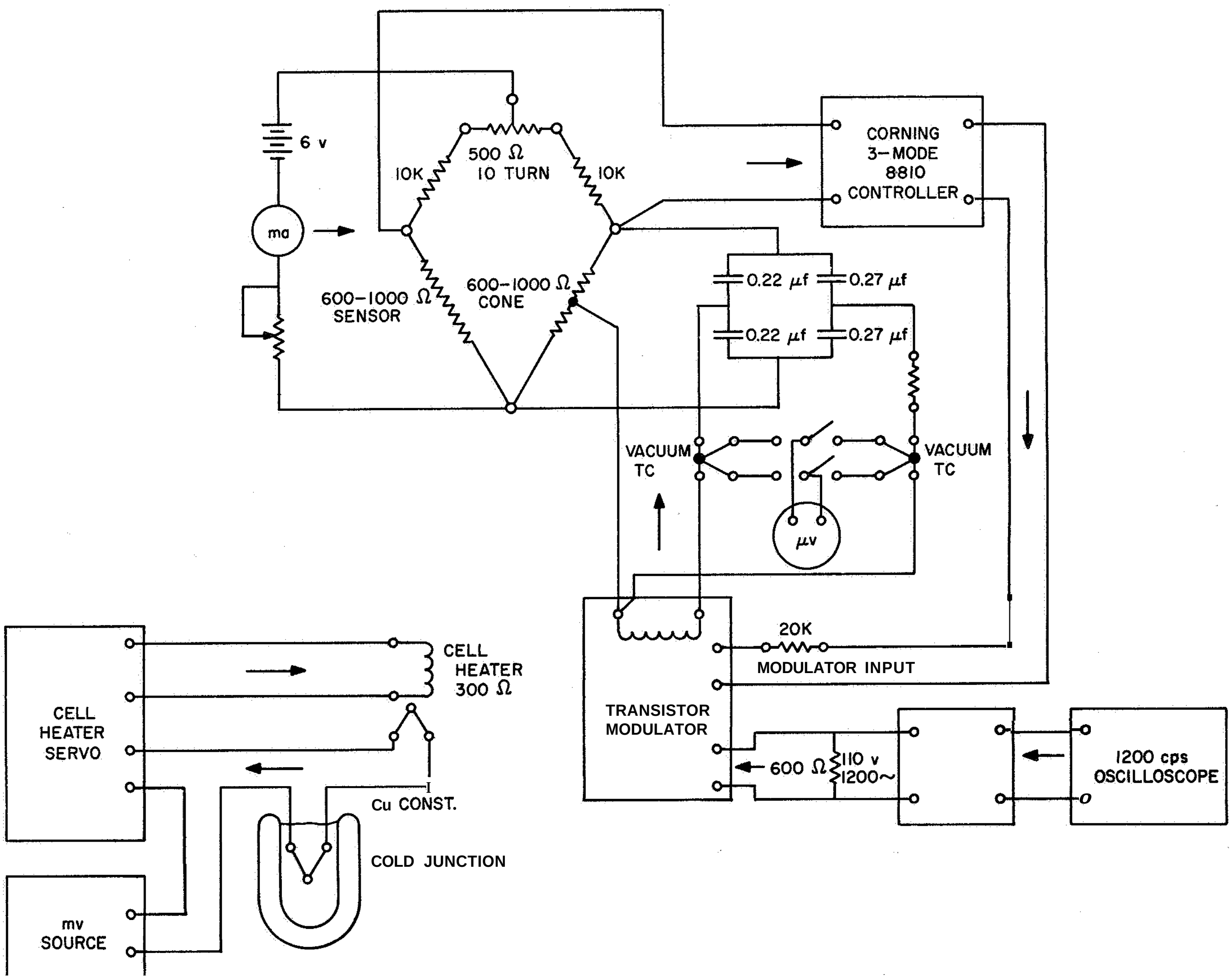


Fig. 1. Side view of ACRAD

Fig. 2. Circuit diagram of ACRAD



SPECTRUM RESEARCH AND SIMULATOR ERROR STUDIES

NASA Work Unit 124-09-05-04-59
JPL 324-90701-2-3750

R. E. Bartera

OBJECTIVE

The goal of this unit is to improve the knowledge of the solar spectrum and total intensity, and to improve the confidence in the instruments used to measure simulated sunlight in space simulators.

SOLAR SPECTRUM MEASUREMENT EXPERIMENT (SSME)

The objective is being pursued through the SSME, in which a flight acceptable version of standard solar simulation instrumentation for measuring both total intensity and spectral distribution has been developed. This equipment is currently scheduled to be flown aboard an X-15 aircraft at altitudes above 70 km in late February 1966. Simultaneous measurements will be attempted with duplicate equipment on the ground along the flight path to measure the spectral distribution of the atmospheric absorption.

The flight hardware consists of a filter/detector block (F/D), signal conditioning and recording apparatus, and the aerodynamic pod with its associated hatch and filter/detector erection mechanism.

FILTER/DETECTOR BLOCK

The F/D contains twelve fast response thermopiles covered with filters and lenses. A contract was let to the Eppley Laboratory, Inc., (JPL 951324) for the design and fabrication of this device. The problems involved in ruggedizing the low mass thermopiles and developing the proper filters was quite difficult but a F/D has been delivered to JPL which has since passed all environmental testing with flying colors. The flight hardware F/D block was delivered to JPL on December 15 and vacuum thermal tests using a mercury-xenon compact arc source as well as atmospheric pressure carbon arc tests were accomplished at JPL. Inclement weather prevented the planned comparison of the F/D flight hardware and a dummy mockup F/D (procured on a previous contract 950929), at Table Mountain against the Angstrom Compensated Pyroheliometers. This test will be accomplished just prior to the first flight.

SIGNAL CONDITIONING EQUIPMENT

During the summer of 1965 a breadboard version of the signal conditioning equipment consisting of a 24-channel reed switch, commutator, differential high-gain DC amplifier, calibration and temperature transducer voltage sources, and DC/DC power converter was completed and temperature-tested. Amplifier stability, data rate, and data readout problems were solved using this breadboard. Thermal and input voltage circuit performance studies were also completed.

Through a series of small procurements the chassis and circuit boards for the flight hardware signal conditioning equipment has been obtained. Final assembly and system testing has been accomplished at this laboratory. The flight hardware was used during the thermal vacuum tests of the flight F/D block and is now undergoing extended vibration, shock, and steady-state acceleration environmental qualification testing while waiting for the flight date.

A major milestone, the X-15 compatibility tests, have been repeatedly postponed because of the unavailability of the aircraft. It is anticipated that this test will be accomplished quite soon.

POD/HATCH AND DETECTOR ERECTION EQUIPMENT

Since the field of view angle of the detectors is only 2 deg and the maneuverability of the X-15 is limited, it is necessary to preset the roll and pitch angle of the F/D block so that it is solar oriented when the X-15 is in a normal horizontal flight. It is also necessary to protect the F/D block during the prelaunch and re-entry portions of the flight. The rear portion of the port pod of the X-15 has been redesigned and fabricated by JPL. In order to investigate the problem of access to the drive mechanism, and to develop the linkage to drive the hatch, an aluminum mockup was fabricated. Based upon the aluminum mockup, modifications of the original design were incorporated into the final Inconel and stainless steel version. The flight F/D support and spring drive mechanism was fabricated as a portion of the aluminum mockup and was used to drive the aluminum hatch system. The flight pod/hatch is undergoing final assembly and environmental testing is now scheduled for January 15, 1966.

REPORTS, PAPERS, AND MILESTONES ACCOMPLISHED

A report concerning the status as of July 1965 was presented at the NASA in-house Solar Simulation Symposium on July 8, 1965. This detailed the design constraints as presented by the X-15 performance parameters and the response of the filter detectors, The design considerations and tradeoff involved were further discussed in a paper entitled "Solar Spectrum Measurement Experiment: System Considerations and Current Status" presented at the 1lth National ISA Aerospace Instrumentation Symposium October 7, 1965. This paper will be included in the symposium proceedings. Attendance at the "Fundamental Radiometry for Experimental Scientist'! course held at the Eppley Laboratory, Inc., in late October 1965 made it possible to discuss the problem of absolute accuracy of calibration with concerned members of the National Bureau of Standards, the National Physical Laboratory, London, and the National Research Council, Canada. The present 2% difference between the theoretical Steffan-Boltzman constant and the experimental verification represents an immediate stumbling block; however, recent work by Dr. Kowstkowski of the National Bureau of Standards as reported at this conference indicates that this uncertainty may be halved in the near future.

The delivery of the flight F/D and its vacuum thermal testing is the major milestone accomplished during this reporting period. Secondary milestones are: the completion and vacuum thermal testing of the flight signal conditioning equipment, and the completion and operation of the dummy pod.

SPACE VEHICLE DESIGN CRITERIA (124-12)

STRUCTURAL-DYNAMICS DESIGN AND TEST CRITERIA
NASA Work Unit 124-12-01-01-55
JPL 324-20101-2-3530
W. H. Gayman

OBJECTIVE

The objective of this work unit is to prepare engineering manuals and/or technical reports on three facets of structural dynamics: (1) space vehicle dynamic loads for the launch and exit phase, (2) modal vibration survey techniques, and (3) control criteria for multiple shaker systems used in environmental vibration testing. The motivation for this effort, all scheduled for completion within FY 1966, is to facilitate the technical management of the dynamics investigations of space vehicle systerns by documenting technical approaches toward more rational structural design and test criteria for spacecraft.

SPACE VEHICLE DYNAMIC LOADS FOR THE LAUNCH AND EXIT PHASE

A contract awarded to General Dynamics/Convair for the preparation of an engineering manual on space vehicle loads during the launch and exit phase was activated at the start of FY 1966. JPL is not merely monitoring this effort but is engaged in a companion effort that will culminate in a document dealing with improved techniques for the technical management of the dynamic loads analyses of complete space vehicles. In particular, the JPL report will present methods of determining normal oscillation modes of space vehicles, the separate stages of which are under the management of different organizational segments of NASA, and are under development by different contractors.

The GD/C engineering manual, representing the greater portion of the total task, will give a general delineation of dynamic loads criteria and analytical techniques for their application.

In both the JPL work and the GD/C work, the Atlas/Centaur/Surveyor space vehicle is being used in illustrative applications. JPL has computed sets of normal oscillation modes of the complete vehicle from suitable mathematical models of the Atlas and Centaur stages, as provided by GD/C, and of the Surveyor spacecraft, as provided by Hughes Aircraft Company from modal vibration surveys. These space-vehicle modal data have been transmitted to GD/C for use in analyses of dynamic response to transient forces associated with thrust buildup and tailoff, stage separation, gust encounterment, etc.

In the execution of this work, from the planning of the contractual statement of work through the completion of the final documentation, it is sought to conduct a "pilot operation" to demonstrate one way of handling the structural-dynamics aspects of physically connected but contractually separate stages of a space vehicle.

MODAL VIBRATION SURVEY TECHNIQUES

During the second half of FY 1966 an engineering manual is to be prepared on the theory and practice of modal vibration testing and data processing. An introductory section will be devoted to the role of this type of testing in the overall program of structural dynamics investigations.

Differences in the objectives, the philosophies, and the equipment characteristics for '!modal vibration surveys'! and ''environmental vibration testing'! will be noted. The importance of meticulous test planning based upon a fundamental understanding of normal oscillation mode theory will be stressed. Techniques of data analysis leading to a check of modal orthogonality will be discussed.

One section will deal with the measurement of structural transfer functions of significance to closed-loop autopilot stability. Considerations in the design of vehicle suspension systems having minimal constraint in the significant rigid-body degrees of freedom will be reviewed.

JPL will prepare this manual from an existing fund of information.

CONTROL CRITERIA FOR MULTIPLE SHAKER SYSTEMS

During FY 1965, JPL conducted, under project funding, a theoretical investigation into the nature of the voltage control problem associated with the use of multiple electrodynamic shaker systems for random vibration testing of spacecraft and large assemblies. In FY 1966 this work is being completed as a portion of the effort on structural design criteria.

The theoretical analysis treats the problem of forced vibration of the test structure by use of normal oscillation modes of the structure and by consideration of the relevant mechanical and electrical characteristics of the attached system of shakers. Equations have been derived to define the driving voltage for each shaker in terms of the specified acceleration power spectral densities and cross power spectral densities at the points of shaker attachment. Numerical analysis has been applied to a simple structure - a uniform beam - under excitation by two asymmetrically placed shakers.

Work in process consists of exploring the use of the analog computer for the synthesis of shaker voltage-control tapes. Experimental evaluation of this concept will be conducted on a simple beam using the JPL's multichannel modal vibration survey system with auxiliary on-hand equipment.

These investigations will be reported in detail in suitable JPL documents.

ELECTRONICS SYSTEMS (125)

GUIDANCE SYSTEMS (125-17)

INERTIAL SENSORS - GAS BEARING GYROS

NASA Work Unit 125-17-01-01-55
JPL 325-70101-2-3440
W. E. Bachman

OBJECTIVE

The objective of this work unit is to develop miniature, single-axis gyros with hydrodynamic gas bearing spin motors, toward a design suited for advanced spacecraft attitude reference systems. Long-life missions, severe environments, and high-performance system specifications are all considered as requirements. In previous spacecraft programs, the gyros available to the system designer have been available guidance-platform, ball-bearing gyros modified to operate in a strapped-down mode. These gyros have not been specially suited to long life, and have not been optimum in size, power, and performance.

HIGH-g GAS BEARING SPINMOTOR DEVELOPMENT

This development effort was directed toward the improvement in load carrying capability of the spinmotor gas bearing in a standard platform-type GG159 single-axis, rate-integrating gyro. This effort was started in mid-1963 as a subcontracted effort with Honeywell, Inc. The high-g shock and vibration development effort was first conducted at the spinmotor level through the use of an instrumented motor mounting fixture that could be mounted directly to either a vibration or shock machine. Initial tests determined motor response characteristics, gimbal transmissibility, and g-level at which bearing contact was made. Results of this testing were used to guide the motor redesign which led to subsequent successful testing at 240-g shock levels.

After completion of the spinmotor fixture testing by Honeywell, further testing was conducted at JPL to verify Honeywell results. In testing at JPL, the motor did not pass 240-g shock inputs without bearing contact. JPL could only demonstrate a capability of approximately 210 g. During this testing the motor mounting fixture was determined to be ringing at the motor natural frequency, so the JPL results were considered to be inconclusive. The motor was also subjected to the Mariner C complex vibration, and passed without any indication of bearing contact. The motor fixture was then returned to Honeywell for cleaning and evaluation, and subsequently received back at JPL for further evaluation. The motor was again shocked at JPL using a vibration machine programmed to deliver shock pulses. Use of the vibration machine allowed shock inputs free of ringing. During this evaluation the thrust bearing was determined to have a maximum capability of only 185 g. In summarizing the shock history on the spinmotor fixture, an apparent relation exists between the number of bearing contacts and the degradation of the g-capability. This relation is shown in Fig. 1.

Examination of the spinmotor bearing surfaces of the motor fixture assembly indicated that the thrust bearing inner circumference had become marked by the repeated bearing contacts under shock input. These scratches caused a gas leak, which is critical to the squeeze film support of the bearing. This squeeze film support is obtained when the rotor moves very quickly, under shock force, and compresses the gas between the surfaces. Marred or scratched surfaces at the edges of this compression area, as was found in the tested motor, allow the gas to leak out faster than the design rate, thus reducing the load carrying capability. No additional evaluation of this original test fixture is presently planned.

HIGH-g GAS BEARING GYRO EVALUATION

The purpose of this task was to build a complete GG159 gas bearing gyro with the improved bearing design and further evaluate the g-capability of the finished product. This gyro was delivered to JPL in January of 1965 and has been under evaluation since that time. The unit is designated as GG159C7 - S/N E-1. Extensive testing of this unit was conducted at JPL in the period between January 1965 and late July 1965, when it was returned to the manufacturer with a failed spinmotor. This evaluation determined normal g-sensitive and non-g-sensitive drift rate parameters along with many temperature and pump frequency sensitivities of the gyro. The following is a data summary of this evaluation.

Ave. g-sensitive drift rate along input axis.	$0.503°/hr/g$
Ave. g-sensitive drift rate along spin axis	$0.063°/hr/g$
Ave. g-insensitive drift rate	$0.073°/hr$
Fluid torque/pump current sensitivity	$0.002°/hr/ma$
Fluid torque/pump frequency sensitivity	$0.011°/hr/cps$
Gyro step response	12 millisec
g-sensitive drift rate/temperature sensitivity	$0.03°/hr/°F$
Random drift average	$0.008°/hr$
Anisoelastic drift average	$0.04°/hr/g^2$
Anisoelastic drift/temperature sensitivity	$0.001°/hr/g^2/°F$

During gyro testing in June 1965 the gyro spinmotor failed to start on two occasions. On the first occasion the motor was successfully started while simultaneously tapping the gyro and applying 44 v to the motor. On the second occasion the motor could not be started by tapping, at different temperatures from 40 to 130°F and by overvoltaging to 55 v for a few seconds. The gyro was subsequently returned to Honeywell for teardown and failure analysis. The teardown resulted in the conclusion that the gyro had been subjected to an extremely high-g shock level at some time resulting in a chipped rotor, a cracked bearing shaft pillow block, and a cracked gimbal case. Figures 2 and 3 show the rotor and pillow block fractures in detail. Whether the damage occurred at JPL, in transit, or at Honeywell cannot be conclusively determined. Negotiations are presently in process to arrive at a repair purchase order at which time the gyro will be rebuilt and returned to JPL for further evaluation.

SCALE FACTOR, PUMP, AND SUSPENSION IMPROVEMENTS

The purpose of these improvements was to further enhance the capability of the GG159 gas bearing gyro for future spacecraft system usage. Details of each of these improvement areas were discussed in JPL TM 33-243, Vol. II. Plans and a preliminary work statement are in preparation for a contemplated procurement of two GG159 gyros with these improvements incorporated as well as results of the previous work in high-g bearing capability and thermal sterilization capability (funded by NASA Task 186-58-02-03).

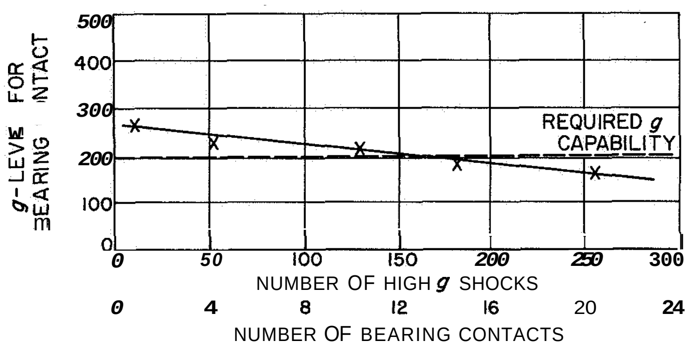


Fig. 1. Shock history

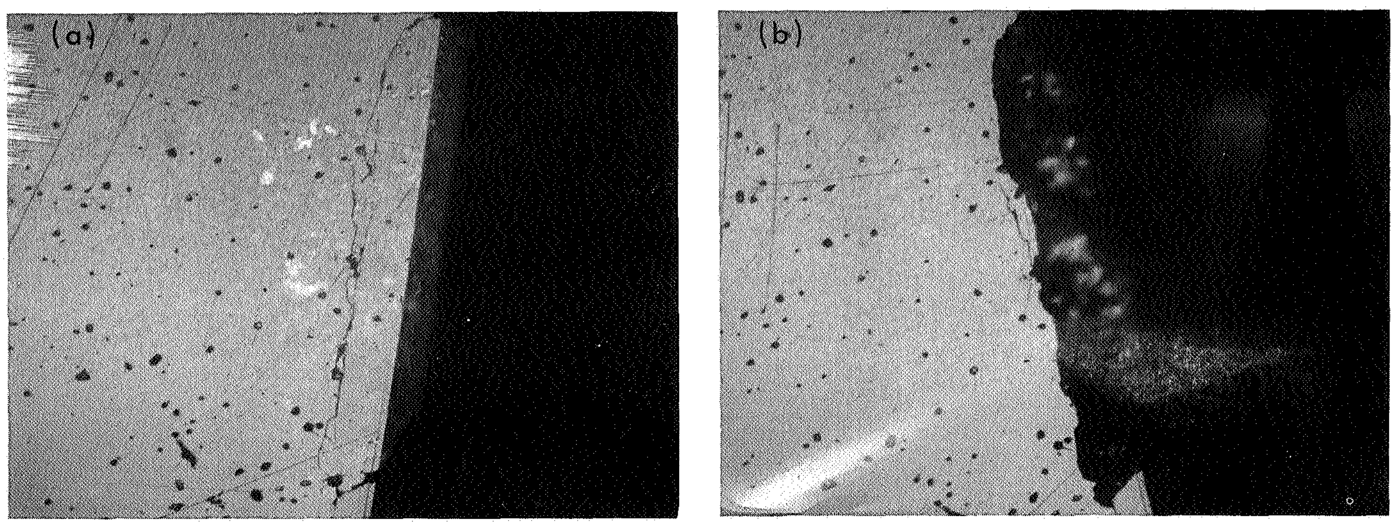


Fig. 2. Rotor chip (80x); (a) as disassembled, (b) after gaging

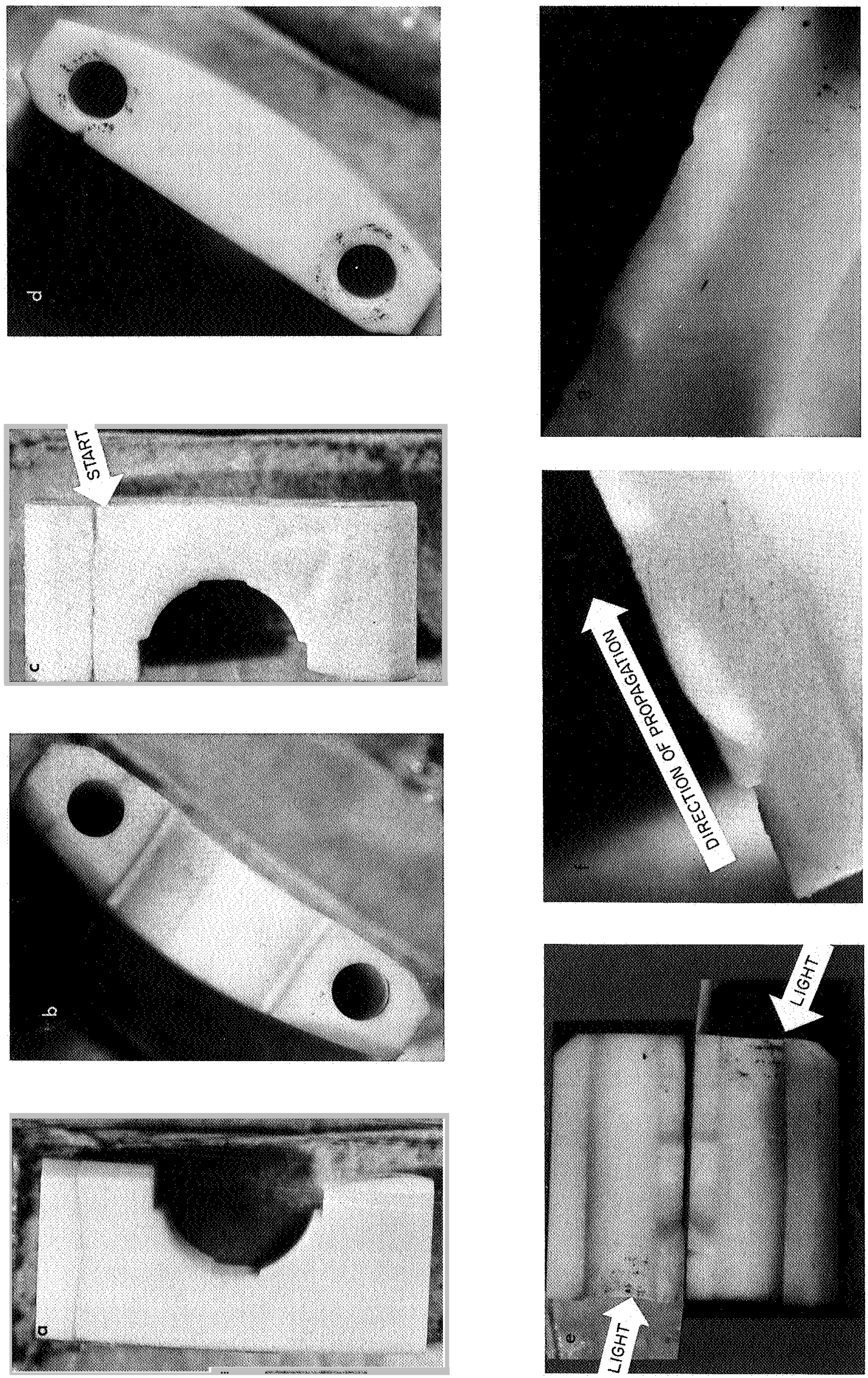


Fig. 3. Pillow block fracture details. (a) 7x. (b) 8x. (c) 7x. Note missing pieces. (d) 8x. Note missing piece. (e) 10x. Crack opened as a book opens. Light sources as shown. (f) 25x. Major piece. Crack configuration indicates direction of propagation, hence also the starting surface. (g) 25x. Minor piece.

INERTIAL SENSORS – ELECTRICALLY SUSPENDED GYRO

NASA Work Unit 125-17-01-02-55
JPL 325-70501-2-3440

T. J. Donlin

OBJECTIVE

The objectives under this work unit are to develop a strapdown electrically suspended gyro (ESG) to an inertial two axis, angular reference sensor for spacecraft and capsule attitude control. Design areas being stressed are simplicity, long life and low power while yielding accuracy consistent with, or better than, conventional strapdown gyros, The ESG will provide inertial reference to the attitude control system during periods of spacecraft maneuvering. Present plans are to progress from a development model of the ESG to a flight-type prototype ESG capable of flight hardware evaluation.

PHASES OF EFFORT

The effort started on the basis of gimbaled ESG technology and was divided into four phases. The first phase was a study, taking typical spacecraft environmental requirements and doing a tradeoff analysis where ESG performance and complexity were considered. The second phase was the building of breadboards, testing of the breadboards, and continuing development in areas highlighted by the study phase.

The third phase was a complete strapdown gyro breadboard build and performance evaluation. In the first three phases, the feasibility of a strapdown ESG was established. A suspension system capable of low-power operation in a low-g environment was developed. A means of automatically starting the ESG in space was established. A breadboard gyro was built.

CURRENT EFFORT

The fourth phase, in progress during the reporting period, has the following objectives:

1. Complete the breadboard gyro so that it is a flight-type ESG.
2. Build a second ESG identical to the first.
3. Develop automatic gyro starting circuitry.
4. Design, build, and check out two consoles for operating the ESG.
5. Design, build, and check out one data processor for obtaining and recording data from the two ESG's.
6. Develop and check out the necessary computer programs for the data processor.

The current effort is under JPL Contracts 951148 and 951149 to Honeywell, Inc., Aeronautical Division, Minneapolis, Minnesota. The effort under these contracts is expected to be complete by June 1, 1966.

PROTOTYPE ESG DEVELOPMENT

To complete the breadboard gyro to a prototype model required the following:

1. Addition of a third optical pickoff for determining spin axis orientation. During the study phase and breadboard testing, it was demonstrated that two optical pickoffs were insufficient to give accurate angular information on the position of the spin axis of the rotor when one pickoff was looking at the rotor in the rotor polar region. A third pickoff was necessary to give an accurate rotor spin axis angular position for any region of rotor readout.

2. The getter - ion pump was incorporated into the gyro package. During breadboard build and testing, a vacuum pumping system external to the ESG was used. This facilitated the breadboard phase as the laboratory vacuum pumping system was available. The ion pump was added to sever the ESG from an external pumping system. The getter - ion pump added to the strapdown ESG is the same as the pump used in another ESG design.

3. Larger rotor spin coils and rotor damping coils were substituted. During the breadboard phase, it was demonstrated that better control of rotor spinup and spin axis wobble damping was required. The new larger coils were designed to give better performance with less power and would cause less heating of the gyro. Lower heating would allow the gyro to temperature stabilize more rapidly.

4. A mounting reference on the case of the gyro was required. This mounting reference was necessary so that the location of the optical pickoffs of the ESG were accurately known and could be positioned in a desired manner with regard to inertial coordinates. The means used were two flat mirrors, each in line with and normal to a pickoff axis and on the opposite side of the gyro from the pickoff. Two mirror surfaces are at right angles to each other and are enough to accurately position the ESG as the third pickoff is orthogonal to both mirrors.

5. The readout pickoffs start a timing sequence by detecting a change in light being reflected from the rotor when the readout line on the rotor passes through the light. If a given level of voltage out of the pickoff is required to start the timing, then the time measured would be dependent upon the level change in light reflected. That is, a lower level of light change would take the same time as a high level of light change. Thus the time required to reach the trigger level for a low level light change would be longer than the time required to reach the trigger level for the high level light change. A height insensitive trigger was incorporated into the

readout electronics to minimize this source of error. The height insensitive trigger was shown to always trigger when half of the pickoff final level was reached.

SECOND ESG

A second ESG is being built identical to the first to facilitate the program. All test data from both gyros can be compared, and a greater confidence in test results and analysis would result. If one of the gyros should experience failure, repair time could extend up to 6 months. The second gyro on hand would allow continued effort during the period of any necessary repair.

AUTOMATIC-START DEVELOPMENT

Automatic-start capability of the ESG required the solution of the "upside down" rotor position. The ESG rotor has a preferred spin axis, but it can spin up with either pole in the so-called up position. The readout system used to measure the location of the spin axis detects the trailing edge of the pattern line to start its time sequence. If the readout compensation is set for one direction of readout crossing the pattern line, the opposite direction of crossing can present errors. These errors are caused by difference in width of the line and difference in line edge definition. Automatic start circuitry to accomplish a single direction of pattern movement under the pickoff would be cumbersome, of questionable reliability, and difficult to implement. All pattern lines heretofore had sharp definition on only one edge. Starting the ESG required manual operation of a skilled nature to accomplish the desired rotor pole "upside up" position.

The rotor patterning procedure was changed to take two passes in opposite directions of the line to get good definition on both edges and control the width of the line. The two passes overlapped each other from 50% near the pole region end of the line to 37% at the equator. When this was accomplished, automatic start of the ESG was possible. The automatic start has the following features.

1. The starting system provides its own time reference from an integral counter. Command intervals for start are as long as 1.5 hr.

2. Complete manual override and control of the automatic starting system is provided to facilitate check and test of the system.

3. A failsafe operation has been selected. This is to prevent power interruptions or momentary relay closures having an adverse effect on the ESG.

4. An internal interlock prevents the application of spin power to the ESG until the suspension systems are operating properly.

5. After the ESG is started, the automatic starting system is disengaged and turned off.

The automatic-start system performs its function by issuing commands to the control console.

CONTROL CONSOLE DEVELOPMENT

The control console for the ESG provides power for rotor suspension, pickoff lamps, and rotor damping. The functions the console performs are rotor spinup and damping, vacuum control and vacuum indication, degaussing of the ESG, and interface with the automatic start. The control console has meter indication of all its control power and control functions. The control console also provides the three gyro pick-off output voltages to the data processor. This effort is for two identical consoles. One is complete and in checkout and the second is nearing completion.

DATA PROCESSOR DEVELOPMENT

The data processor records test data for two ESG's by scanning and routing ESG performance data to a paper tape punch. A typed page copy of the data is produced immediately by a Flexowriter. The punch paper tape is used for computer operation and the Flexowriter gives information for realtime plotting of data during a gyro run and an indication if marginal gyro operation exists. The data processor can handle two strapdown ESG's. The data processor consists of two 100 Mc counters, two panels of logic and logic control circuitry, a precision frequency standard, a digital voltmeter, a tape punch, a Flexowriter, and two panels of power supplies. The design of the data processor is complete. The assembly of the data processor will be completed at the beginning of the next reporting period.

COMPUTER PROGRAM DEVELOPMENT

The use of a computer is necessary to take the gyro output and analyze it for ESG performance. The computer to be used is the Honeywell H-1800 and seven corn-puter programs are under development to accomplish the ESG performance analysis. Four of the programs edit and transform the data for performance analysis:

1. Data Recode and Preliminary Edit. This program accepts the data fromthe test station data processor and puts it out in alpha-numeric code. This program also monitors the data for errors in general format. The errors are flagged for the next program.

2. Edit and Preliminary Calculations. This program deletes data points that have errors in format. It also edits the counter data and deletes those data points whose information does not satisfy logical criteria. Spin axis direction cosines in pickoff axis coordinates are calculated and the output is in a convenient form. Compensation for pattern errors will be done in this program.

3. Inertial Space Transformation. This program transforms the pickoff axis coordinates to gyro case axis coordinates and then to inertial axis coordinates. If errors between the pickoff axis coordinates and the case axis coordinates exists, compensation will be accomplished in this transformation.

4. Inertial Space Edit. This program enables the manual deletion of any unwanted points from the inertial space data. Events which ark obviously bad because of readout scatter are deleted and not submitted to the performance programs.

Three programs perform the performance analysis of the ESG data prepared by the edit and transformation programs. Each of these programs is designed to accept the inertial data as prepared by the edit and transformation programs:

1. Esg Math Model Program. This program will fit the data to a general mass unbalance and electric torque model in a least-squares sense over a specified portion of the data. This model is then removed from the data of an entire run and the residual error is printed out.

2. Mass Unbalance Compensation and Performance Program. This is a many option program. It can accept the inertial space data or the output of the ESG Math Model Program. For outputs from this program, any or all of the following can be chosen:

   a. Comparison of ESG drift with requirements.

   b. Compensate for mass unbalance.

   c. Compare mass unbalance with requirements.

   d. Compare the data to a time dependent function model so that a prediction of gyro performance based on this comparison can be made.

   e. Perform an analysis of variance on the data.

3. Inertial Space Simulation. This program is a data simulation program which will be used to check out and determine the capabilities of the data reduction. It is essentially the inverse of the ESG Math Model Program.

These programs, with some modification, can be run on the IBM 7094 computer.

PROGRESS

The additions to the breadboard gyro to make it into a flight-type prototype have been accomplished during the reporting period. Some difficulties were experienced. The breadboard rotor surface was damaged so that it was unusable for readout but could be used for rotor suspension tests and interface checks. Another rotor was to be completed and installed by the end of the reporting period.

The placing of the readout rotor pattern on the rotor surface has delayed progress on the ESG. For accurate readout the pattern lines must have a uniform width and sharply defined edges. Various methods have been tried and a sand blast technique has proven, thus far, to be the most advantageous. It requires considerable skill and practice on the part of the individual performing the patterning to mark the pattern properly.

Checkout of the rotor suspension system has not shown any significant problems. Suspension checks were conducted in both a 15-g suspension mode and a 3-g suspension mode. Checkout of the readout system has shown high noise in the system. This high noise is due to the damaged surface of the rotor being used. There is also false triggering of the readout system by the pattern on the rotor. Both of these conditions should clear up when the new rotor with improved pattern is installed. Spinup checks have shown that the spinup rate is 25 revolutions/sec/min. This compares with the anticipated rate of 20 revolutions/sec/min. No drift checks will be run on the ESG until the new rotor has been installed.

PLANS FOR NEXT REPORT PERIOD

Completion of the present effort is expected in the next reporting period. Upon completion of the ESG's, readout system tests and alignment will be done. Next the drift and environmental tests will be run. Following will be the gyro starting tests. Finally the gyro suspension vibration and acceleration tests will be run.

A test program effort will be added to gather complete test data, reduce the data, and perform an analysis of this test data. This effort will also be performed by Honeywell, Inc. The test program contemplated will have the following:

1. Drift Stability and Repeatability Tests. A series of tests will be conducted to determine the long-term stability and repeatability of the ESG drift characteristics. The results will be reduced and analyzed and this information will be used to project the effects on the gyro during space flight.

2. Temperature Tests. Temperature variations will be applied to the ESG, and data on the effects on vacuum seals, alignment angles, and drift performance will be analyzed.

3. Power Supply Variation Tests. Suspension power supply voltages will be varied and the effect on gyro performance will be studied to determine maximum safe variations.

4. Gyro Motion Tests. Tests will be performed in the laboratory to determine vehicle motion effects on gyro performance.

5. Vibration Drift Test, Vibration tests will be run on the gyro to determine the effects upon the drift behavior of the gyro. Vibration will be held at levels that present no hazard to the suspension capability of the gyro.

6. Vibration and Shock Stability Tests. Tests will be conducted to determine the effects of launch and separation environments of vibration and shock on gyro vacuum seals, pickoff alignment and operation, and gyro drift.

7. Test Plan and Procedures. A test plan and detailed procedures will be written to conduct a complete laboratory performance evaluation of the ESG. The test plan will also include a list of all required test instrumentation and complete test instructions.

8. Test Mounting Fixture. A mounting fixture to conduct all tests will be fabricated and delivered.

9. <u>Instruction and Training</u>. Two JPL personnel will be instructed and trained in the operation and test of the ESG. The instruction and training will include classroom instruction and laboratory test operation.

10. <u>Computer Program</u>. The seven computer programs , developed for the ESG and used on the Honeywell H-1800 computer, will be prepared for use in the JPL IBM 7094 computer.

INERTIAL SENSORS — SPACECRAFT CONTROL GYROS

NASA Work Unit 125-17-01-03-55
JPL 325-70601-2-3440

W. E. Bachman

OBJECTIVE

This work unit is directed toward investigation and/or evaluation of research-type and newly developed attitude control sensors that show potential for significant improvement over currently available sensors in the areas of simplicity, size, power, and life, while providing improved or equivalent performance. The instruments under support have been the Litton vibrating rotor gyro and the Autonetics vibrating string gyro. Both of these concepts were judged to be less complex than current floated attitude control gyros. In addition, the vibrating string gyro was considered to be potentially a very low power, long-life instrument, and the Litton gyro had potential for long life with the use of gas bearings.

VIBRAROTOR GYRO

The purpose of this task was to evaluate the Vibrarotor gyro design by Litton Industries at JPL for a better understanding of gyro mechanization, performance characteristics, and potential as a spacecraft control sensor. Although the gyro was delivered to JPL in June 1965, it has not as yet been evaluated due to being held up until the JPL Procurement Section could resolve a settlement with Litton Industries. This settlement was to obtain an equitable reduction in price of the gyro because the final gyro performance did not meet the JPL purchase specification. This settlement was reached during the first week in December and preparations are now under way to start testing at JPL. Further discussions are planned with Litton regarding operating procedures and with Holloman AFB Inertial Test Facility, where two Litton Vibrarotor gyros have been evaluated.

STAR GYRO

The purpose of the Autonetics STAR gyro effort was to determine the potential capability of using the vibrating string approach in a strapdown gyro configuration. The important results of the study effort were discussed in JPL TM 33-243, Vol. 11. A final report of the study contract; was received from Autonetics in July 1965. Subsequent to the receipt of the final report it was determined from Autonetics that both USAF funding and Autonetics in-house funding on the STAR gyro concept were being discontinued, due to design problems for which solutions were not apparent. A JPL decision to continue with the STAR gyro development has not been made and appears unlikely.

NEW CONCEPTS

An investigation has been under way since the beginning of the fiscal year to find new sensor devices which have potential for spacecraft control. A letter of interest was sent from JPL to a wide distribution throughout the inertial sensor industry which is just beginning to provide new information. Although the investigation is not limited to single-axis gyros, a number of new wide-angle designs have come to light and are being further studied, At least one subminiature rate-integrating gyro appears to be extremely attractive from the point of view of power, weight, and size. It is presently anticipated that from this investigation will come several new areas of interest for which procurement action will be initiated in the third quarter.

STRAPDOWN ELECTROSTATIC GYRO AEROSPACE NAVIGATION SYSTEM

NASA Work Unit 125-17-01-04-55
JPL 325-70901-2-3404

H. C. Vivian

OBJECTIVES

The strapdown electrostatic gyro aerospace navigation (SEAN) system development program is a new work unit which received NASA Headquarters approval during the second quarter of FY 1966. It is a joint NASA/USAF cooperative effort whose purpose is to develop and establish the feasibility of an inertial navigation system incorporating electrostatically suspended gyros (ESG) whose advanced state of development is the result of both past and current component development programs. By joint agreement, JPL has the responsibility for the system design, fabrication, integration, and test. The Air Force Avionics Laboratory has the responsibility for providing the gyros and associated test equipment, the inertial measurement unit (IMU) frame with ancilliary electronics, and test vehicles and facilities for a followon flight test program. Specific objectives for the program are to:

1. Develop and demonstrate in the laboratory the performance of a feasibility model ESG navigation system.

2. Define accuracy criteria for the system and measure system performance in terms of these criteria.

3. Develop system for an accuracy target of 5-nautical-mile error after 5 hr of cruise on an open course.

4. Design system to accommodate X-15 maneuver performance characteristics.

5. Evaluate error sources and effects, and make recommendations for future component and system development.

The effort at JPL has been divided into four subtasks corresponding to the technical discipline structure in the Guidance and Controls Division. The objectives of each subtask precede the following status reports for each activity.

SYSTEM DEVELOPMENT

The objectives of this subtask are to provide the system analysis, functional description, and error analysis for the SEAN system.

System Analysis

The principal purpose of the computer in the SEAN system is to process the input information from external sources, gyros, and velocimeters so as to determine the initial alignment of the system, to determine the location and velocity at any time, and to present these data in a usable form. The computer must be provided with a program which controls the operations required *to* perform these functions. The first step in the development of the program is the definition of those mathematical equations which describe the vehicle motion and the relationships between the variables in the system. The analyses performed in this reporting period are covered in the following paragraphs.

The coordinate system in which the equations of motion are to be integrated was selected. Several possible coordinate systems were investigated. The equations of motion were determined for each, and the relative advantages of each were considered. Factors considered included simplicity of the equations of motion and the ease of transformation of variables both from the sensor measurements and to the desired output quantities. An Earth-equatorial, inertial, Cartesian coordinate system was chosen.

The type of sensor inputs to be received by the computer were defined, and from these the method of transforming the measured vehicle motion into the selected coordinate system was developed. The inputs from the gyro are the direction cosines of the gyro ball spin axis in a body-fixed coordinate system. A method was developed for compensating for known nonorthogonality of the gyro pickoffs and computing the largest direction cosine from the other two to maintain accuracy of the unit vector in the spin direction. A tentative computer program was developed to perform these computations. The direction cosines of the two gyro spin axes are then used to define the transformation from the body-fixed coordinate system to an inertial coordinate system related to the spin axes. The transformation from this coordinate system to the inertial coordinate system selected for integration is obtained from the alignment procedure described later in this report.

Since the motion of the vehicle is measured by **3** orthogonal body-fixed velocimeters the vehicle accelerations are integrated along curved paths in inertial space. These integrals must be transformed into integrals along the inertial coordinate axes. Several methods were considered for doing this. In the method selected, the velocimeter data is differentiated to obtain body-fixed accelerations that are then transformed into the inertial coordinate as described previously.

The methods of numerical differentiation and integration to be used were investigated, and methods based on the use of backward difference tables have been selected. The order of the processes were studied considereing the accuracy of the computations, possible dynamic variations in the inputs, and the integration cycle time of the computer.

Another acceleration input to the equations of motion of the vehicle is the gravitational acceleration. The characteristics of the Earth's gravity potential were studied, and equations were written for several degrees of approximation. Although more study is needed to determine the required gravity-model accuracy, a tentative model which includes the first zonal harmonic of the gravity potential has been selected.

Several methods have been studied for determining the orientation of the body-fixed coordinate system with respect *to* the inertial coordinate system. The majority of the effort has been directed to a system that uses the apparent precession of the inertially fixed gyro spin axes while the vehicle is motionless on the surface of the Earth to determine the direction of the Earth's spin vector. The velocimeter outputs are used to define the local plumb-line vertical in body coordinates. These two vectors are used to define the orientation of the body in inertial coordinates. Gyro measurements give the orientation of the spin-axis-related, inertial coordinates in the body system. From these relative coordinate system orientations, the spin-axis inertial coordinate system is defined in inertial coordinates allowing the transformation of the acceleration from body coordinates to inertial coordinates required for the navigation computation. Techniques for compensating systematic inertial instrument errors require further investigation. Methods developed under Air Force contract will be reviewed for potential implementation into the navigation computer program.

System Development

A preliminary system functional block diagram has been developed which shows the major sections and information flow of the navigation system. This block diagram is shown in Fig. 1.

Future work will be directed toward obtaining a more detailed information flow diagram and integrating the results of existing analyses into a consistent set of procedures and equations for performing the navigation computations. This will involve completing the details of the current preliminary results and performing the analysis of the logic and interfaces between the various system functional elements. The results of this work will be employed in the preparation of the system functional specification scheduled for release in the third quarter of FY 1966.

A system error analysis is to be made to evaluate the effects on system performance of sensor errors, numerical computation accuracy, computer cycle time, and approximations as in the gravity-model.

IMU DEVELOPMENT

The objective of this subtask is to provide the SEAN system inertial measurement unit (IMU) and appropriate test equipment as a completely designed, integrated, assembled, and tested subsystem. Tasks associated with this effort include: (1) the procurement and qualification of inertial elements, (2) definition and integration of the IMU subsystem, subassemblies, and test equipment, (3) preparation of IMU test procedures and test facilities, and (4) coordination with the Air Force Avionics Laboratory in the development of IMU subsystem equipment.

Coordination meetings were held with the Air Force in July and November, and with NASA Headquarters and the Air Force in October. From these meetings, areas of participation by both NASA/JPL and the Air Force Avionics Laboratory were defined and program objectives established. Gyro and accelerometer specifications developed by Minneapolis-Honeywell under the system development task of the current Avionics Laboratory contract have been received. JPL recommendations of task definitions for the forthcoming Air Force FY 1966 statement of work were prepared late in December. These will be reviewed at the next AF/JPL coordination meeting to be held at Holloman AFB in January.

Digital Velocimeter Procurement

The goals which have been set for required navigation performance in this system need acceleration and velocity measurements of a very high accuracy level. With this requirement in mind a design specification (XOV-50475-DSN) was written which sets forth performance demands just equal to the state of the art in existing digital accelerometers. Pendulous integrating gyro accelerometers (PIGA), which might provide slightly better performance, were ruled out at the beginning because of complexity, power, weight, and cost.

In brief, the velocimeter performance requirements are as follows:

Bias . . . . ±30 micro g(mean)

Bias stability . . . . 30 micro g (1 sigma)

Scale factor . . . . ±0.01%

Scale factor stability . . . . . ±0.005% (1 sigma)

Linearity . . . . 0.005% to 10 g

This specification was sent, as part of an RFP, to three major inertial sensor manufacturers. These were Bell Aerosystems, Kearfott Division of General Precision Instrument, and Honeywell Inc. All three companies responded with proposals, and the Bell Aerosystems design was selected.

Negotiations were initiated on November 10 and are not yet complete. At the present time the procurement is pending agreement on terms, warrant, and price.

ESG Technology Familiarization

To develop at JPL a complete familiarity with the techniques of ESG operation, work has been done to improve and operate the gyro built by GE under the first JPL/NASA feasibility program (Contract NASw-384). The effort during this period has been:

1. Vacuum improvement. Numerous vacuum leaks have been found in the gyro enclosure. These leaks have been localized and suitable sealants selected that will withstand the bakeout cycle (300°F for 72 hr). An improved vacuum pump has been installed on the gyro which will handle a larger outgassing load and which does not require a hot filament.

2. Gyro cleaning. Operation of this gyro at the contractor's was continually interrupted due to problems with contamination in the vacuum enclosure. Work has been done to ensure the removal of all loose particles from the gyro and to develop procedures to obtain an acceptable level of cleanliness on all interior gyro surfaces.

3. Suspension system. The gyro suspension system (Fig. 2 and 3) has been repaired, the cabling has been rewired, and preliminary electrical checkout has been completed.

4. Readout electronics and recorder (Fig. 4 and 5). The optical readout preamplifiers, scratch filter, and multiplex switch have been reassembled and checked for proper operation. The readout recorder, which was developed for a previous program, has been modified and recabled.

5. Power supply. A failsafe power supply, built for a previous gyro, has been modified for this program (Fig. 6). This unit will assure a continuous source of power for the suspension system in the case of commercial power line failure.

During the next period, the gyro will be cleaned and assembled, first with an imperfect rotor, and the suspension system operation will be verified. This will include electrical simulation of vibration environment and determination of the frequency gain characteristic of the suspension system. The optical readouts will be aligned, and adjustments on the readout electronics accomplished. The rotor will then be replaced by the best available, and the checkout of the complete readout system will be accomplished.

COMPUTER DEVELOPMENT

The objective of this subtask is to develop the computing system required to convert the measurements provided by a strapdown inertial measuring unit to position information in Earth coordinates. Four efforts are required to fulfill this objective. Two are equipment development involving the conditioning of the inertial measuring unit data to computer format and the adapting of computer output data to a position display. The other two are the definition and procurement of a general purpose airborne digital computer and the development of software required for the overall reference frame conversion and navigation processes.

Equipment Development

The effort during this period has been in the study and preliminary design of the inertial measuring unit (IMU) to computer adaptor. This adaptor must accept pulse signals from the gyro photoelectric sensors and convert the times between the information pulses to whole numbers which are representative of the direction cosines of the gyro ball spin vector relative to the body coordinates. The conversion of the times to functions of the spin vector involves taking the ratio of the pulse intervals to the total ball period.

Three systems were studied. The first two were automatic frequency-lock and phase-lock systems which avoided arithmetic division by allowing the ball rotation period to control the counting rate of pulse interval counters. The third system is a sample-and-hold system which uses a constant counting frequency and requires the performance of arithmetic division of the pulse intervals by the ball period.

The automatic systems were rejected in favor of the fixed-frequency system because no reduction in hardware was forseen over the third system, digital-to-analog conversion was needed, and the required precision could not be maintained during extreme maneuvers of the vehicle. A tentative design for a fixed frequency system has been established utilizing integrated circuits, and a breadboard of this system will be fabricated in the next period.

The hardware required to condition the velocimeter output is relatively simple, and logic design and breadboard construction will be accomplished within the next three months. Work on the output display system is awaiting the definition of detailed interface requirements. The equipment design will be started as soon as the computer output is specified.

Computer

A specification delineating the functional and physical requirements for the general-purpose digital computer is in preparation. This specification is scheduled for completion by the end of January 1966. A suitable machine will be procured for availability in fiscal year 1967. Computer programming requirements are scheduled for definition by the end of the third quarter of FY 1966, and at that time programming support will be solicited.

PHYSICAL AND TEST INTEGRATION

Objectives

The objectives of this subtask are: to determine the physical limits of the test vehicle environment which the SEAN system will encounter, to prepare environmental test plans to assure that the hardware will survive and function in this environment, to furnish system test and flight test operational support equipment to the project, to prepare test plans for system and flight tests, and to supervise these tests.

Test Vehicle Environment

A review of the general specifications for environmental testing of aeronautical and aerospace electronic equipment is under way, and excerpts from MIL-E-52726 have been issued as design guides. It is intended that the SEAN system be designed and qualified for an environment which is composite of the X-15, F-106, C-130, and 6-131 test vehicles environment.

In October, a visit was made to Edwards Air Force Base to gather relevant data on the X-15 vehicle. A visit to the CIGTF at Holloman is planned to obtain information on other potential flight test vehicles and to review current Air Force test plans and facilities. Release of a detail specification for the environment of the SEAN system is planned for February 1.

Test Plans

The purposes in formulating preliminary test plans are to establish flight system design requirements imposed by the flight test phase, to define system test equipment needs, and to determine range instrumentation requirements. It is intended that useful information gained from early planning will include the delineations of system monitoring points, establishment of preliminary flight profiles, determination of environmental, RFI and power system compatibility requirements, specification of test equipment, definition of range tracking accuracy needs, synchronization, etc.

Present plans call for test flights on Air Force vehicles operating out of Holloman Air Force Base and contact has been made with the Guidance Operations Office at HAFB. This Office has provided preliminary information describing the Central Inertial Guidance Test Facility (CIGTF), potential test vehicles, and procedures, flight profiles and equipment presently in use at the facility. A review of available material on flight testing of inertial guidance systems in general, and ESG navigation systems in particular, is in process, and release of a preliminary plan for the SEAN system is scheduled during the third quarter of FY 1966.

Facility requirements for in-house system and component testing are being explored with regard to security and environment control. Preliminary plans and schedules for the use of in-house facilities are now being formulated.

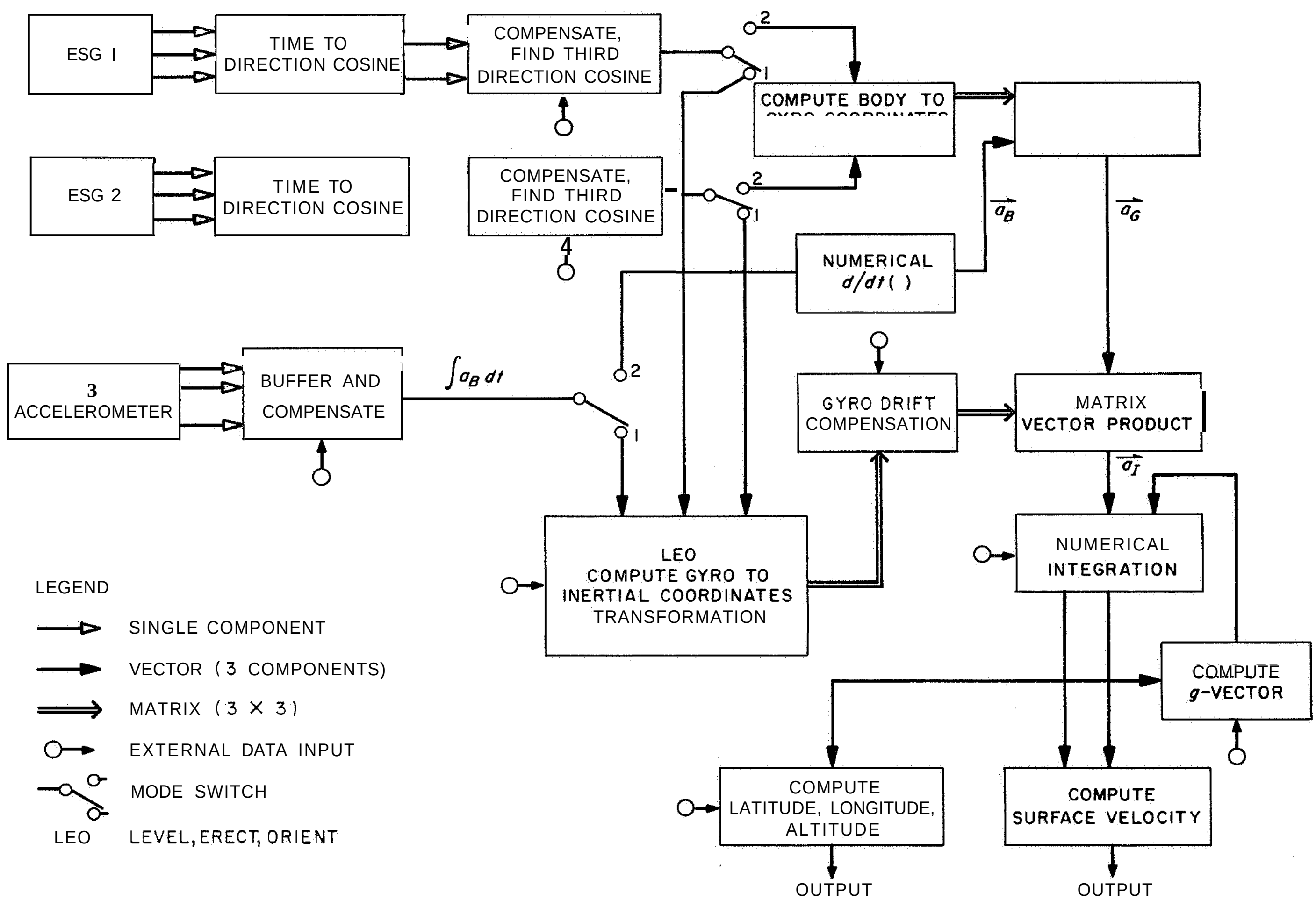


Fig. 1. Block diagram

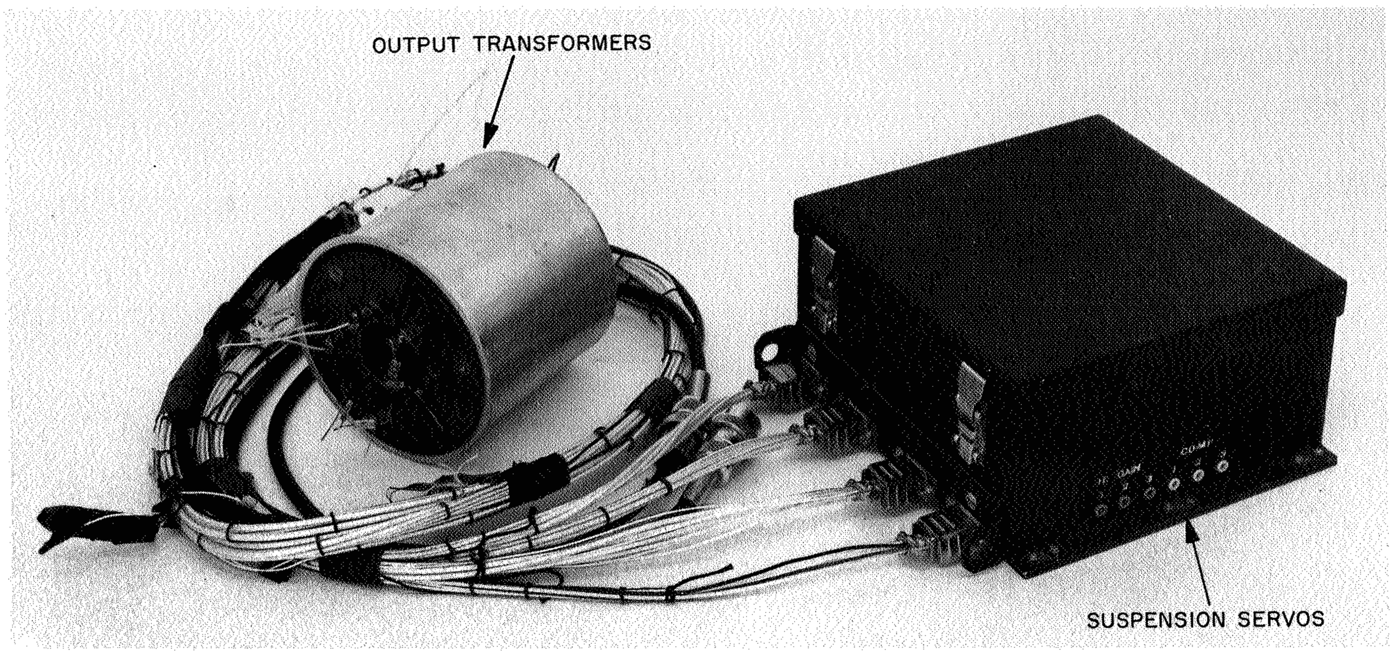


Fig. 2. Suspension system

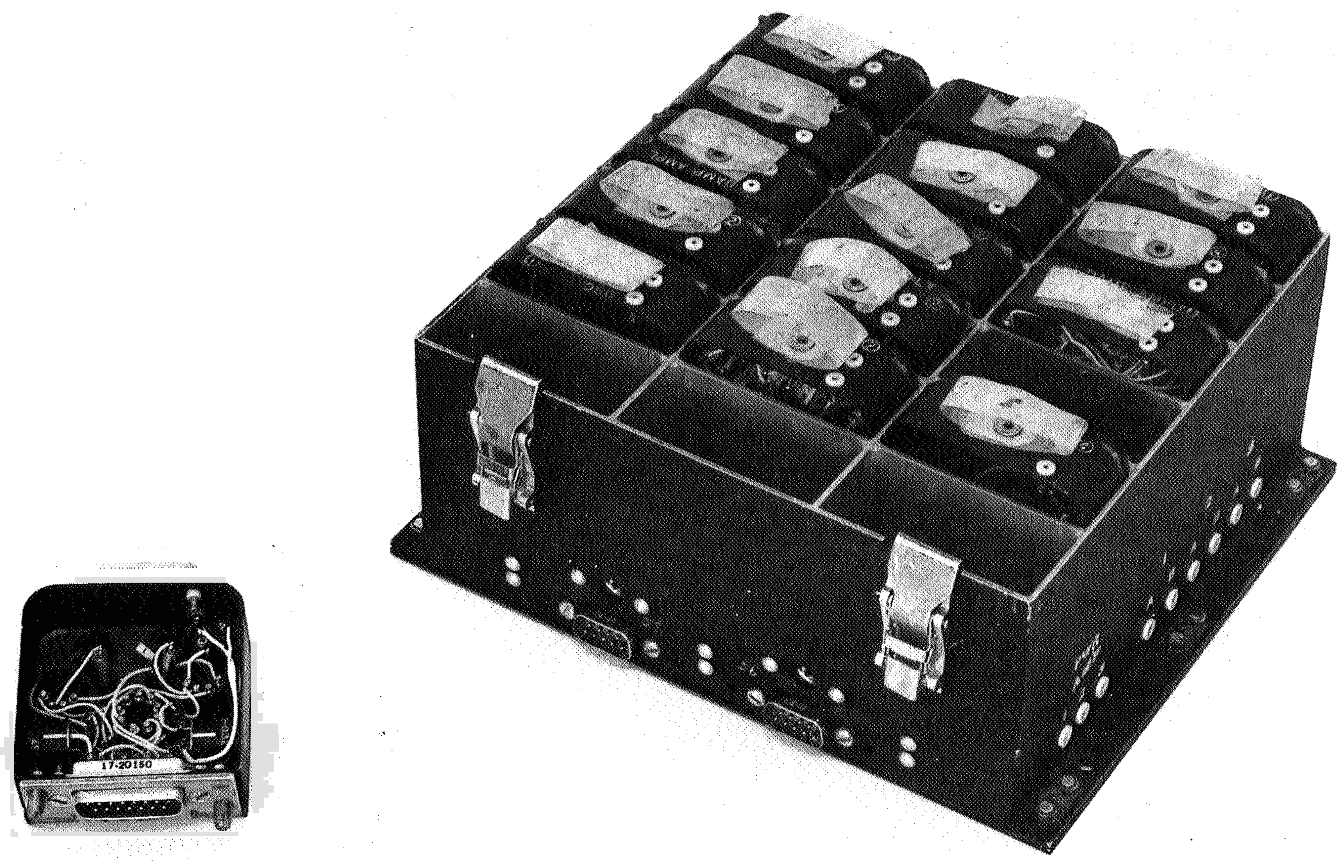


Fig. 3. Suspension **servos**

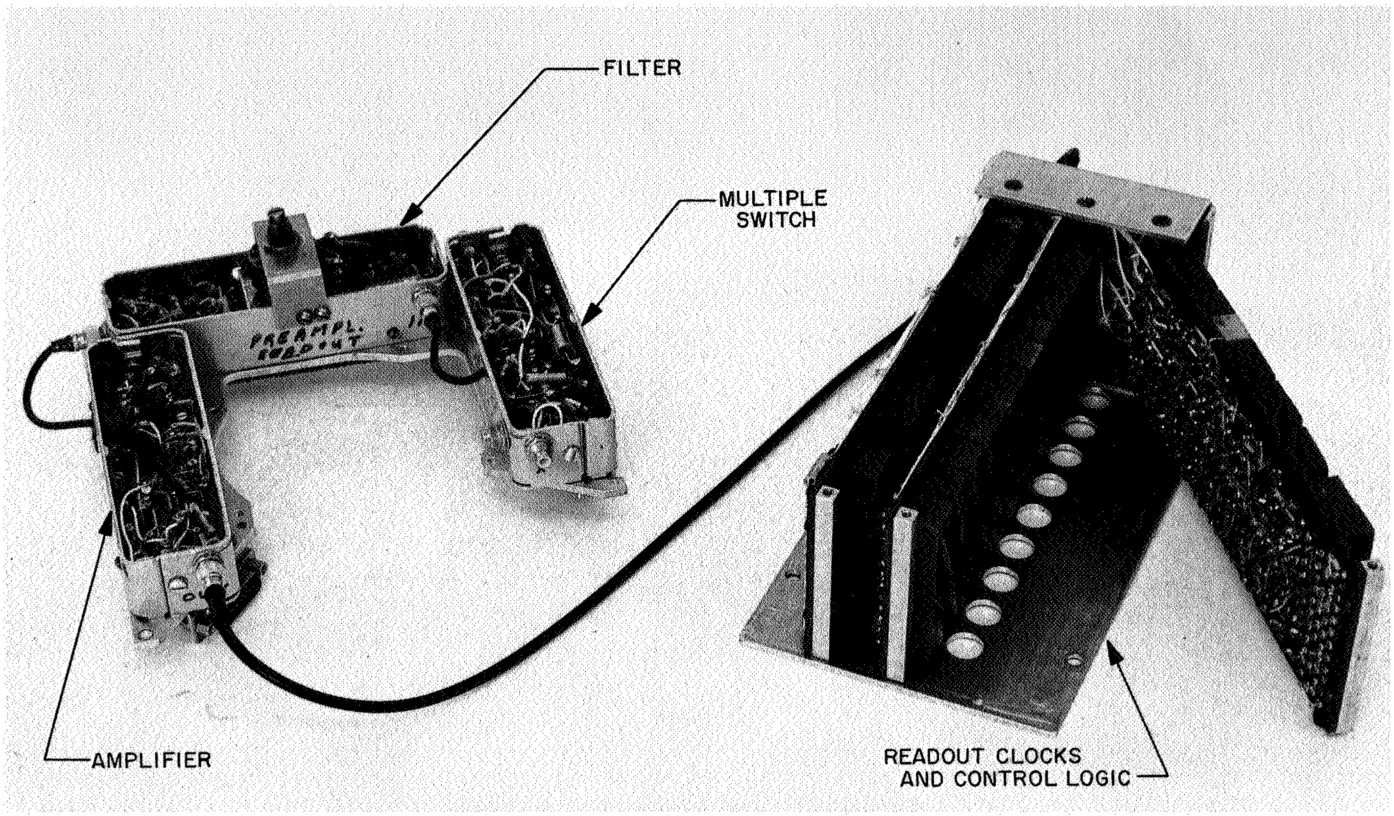


Fig. 4. Readout electronics

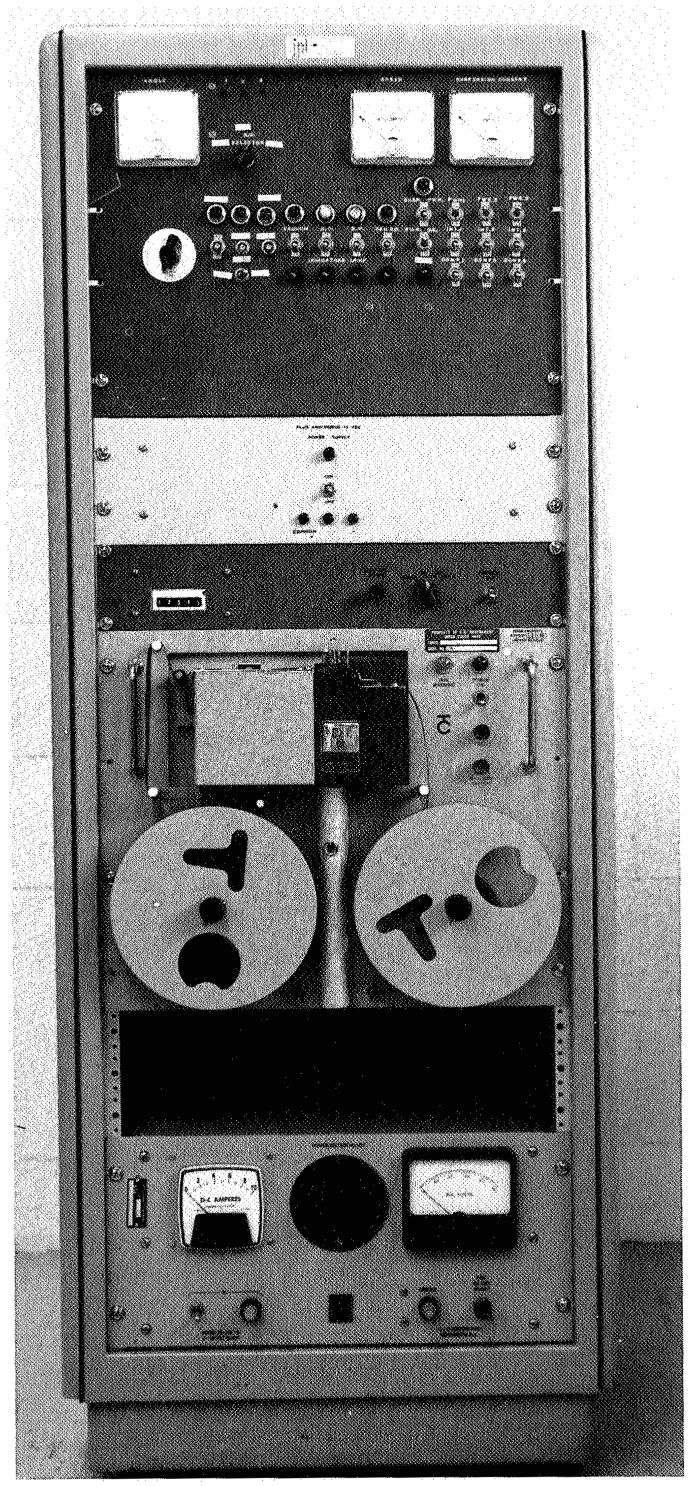


Fig. 5. Readout recording and suspension control panel

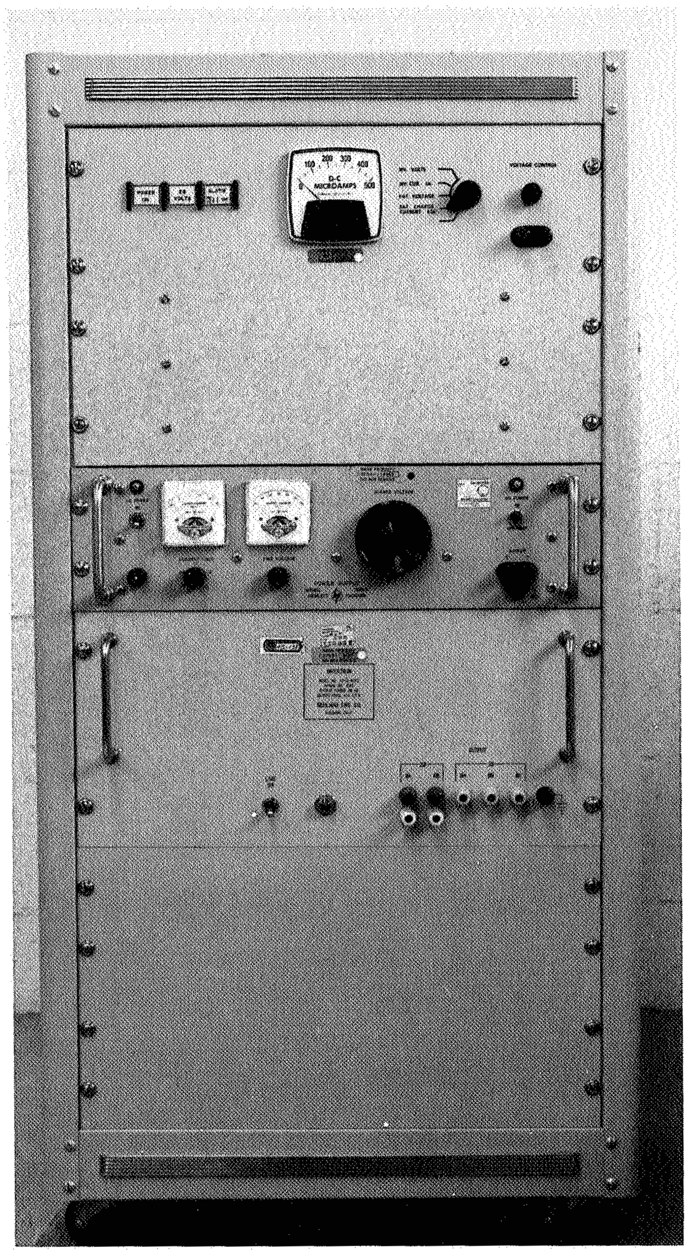


Fig. 6. Failsafe power supply

APPROACH GUIDANCE PLANET SCANNER STUDY

NASA Work Unit 125-17-02-01-55
JPL 325-70801-2-3440
G. E. Hooper

OBJECTIVE

The trajectory of a spacecraft approaching a destination planet can be determined by optical observations of the planet. The objectives of this work unit are the preliminary development of a sensor mechanization to perform these observations and the analysis of the ultimate errors associated with this method of trajectory determination.

SENSOR MECHANIZATION

A study of several possible scan patterns was completed and a computer program was developed that generates the error signal curves. A scan pattern that tracks the sunlit limb of the planet and thereby infers the direction to the planet center has been selected for further development.

A preliminary mechanization has been developed which used the existing Sun sensors and Canopus sensor with the addition of a planet approach tracker. Range to the planet is derived from radio tracking.

The approach guidance measurement phase for this mechanization consists of one sample per minute of each measurement from two days until one day before planet encounter.

During the next reporting period the planet center tracking head should be breadboarded and the scan pattern concept and predicted performance should be verified.

ERROR ANALYSIS

In conjunction with a Canopus sensor life test already in progress, samples of the output voltage for a constant input are being recorded over a period of 80 days. This data will be reduced to a power spectral density which will reveal information about the noise and short-term and long-term drifts that can be expected from sensors such as the Canopus tracker and approach planet tracker that utilize an image dissector.

A preliminary error analysis for a typical Mars encounter has been made yielding a value for the uncertainty of the trajectory determination of 25 to 60 km (3σ) depending on the atmospheric model assumed. This value represents a significant improvement over a radio tracking performance estimate of 300 km (3σ).

FUTURE PLANS

During the next reporting period this error analysis should be verified. A detailed simulated data return from the spacecraft will be used to exercise a trajectory calculation program. This data return will be perturbed so as to permit the determination of the influence of uncertainties in the various system parameters on the overall trajectory uncertainty.

An effort will also be made to reduce the uncertainty about the appearance of the Martian atmosphere by the application of Mariner IV data.

MAGNETIC LOGIC COMPUTER DEVELOPMENT

NASA Work Unit 125-17-04-01-55
JPL 325-70201-2-3410

G. R. Hansen, Jr.

OBJECTIVE

The long-range goal of this work unit is to develop and evaluate a potentially reliable, low-power, general-purpose guidance and control digital computer. Inhibit core magnetic logic and a nondestructive readout (NDRO) uniform access time magnetic memory are being used. The computer is intended for use on board spacecraft and will provide sufficient computational capability to calculate and control the necessary course correction maneuvers for planetary orbiting or impacting missions. In addition, the computer will perform the necessary sequencing functions required for contemporary spacecraft.

COMPUTER DEVELOPMENT

The complete inhibit core logic computer system breadboard has been operational for about one year. During the last six months the computer has been operated for over 400 hr. Two open diode component failures have occurred during this period. The breadboard system was constructed of "unscreened" components.

The basic computer logic has been modified by the addition of two commands. These are Load D and Store D which have to do with the decrement (D) register which is used for timing sequencing functions. The D register is the special register which operates independently of the computer and keeps track of the time interval between successive events.

A second logic core rope has been constructed reflecting all logic changes to date. This rope has been designed to be accommodated in a flightworthy package 2.4 x 4.8 X 0.4 in. This package will contain 501 Nand gates with an average fan in of 7 and 27 Or gates all implemented with 676 ferrite memory cores. Testing of the rope is planned for the next period. Each core will be tested individually to verify the wiring, and then the rope will be integrated into the computer breadboard for complete system checkout.

Procurement of 36 transfer circuits in flight packaged modular form has been initiated during this period. It is expected that the units will be delivered during the last quarter of FY 1966, and that they can be incorporated into the computer system breadboard before the end of FY 1966.

Design review and analysis have been initiated on the various circuits used in the computers. About one-third of the circuits have been analyzed resulting in two recommendations for component value changes. The circuits are being analyzed to determine optimum values which will be most tolerant of component and voltage changes.

Programming effort has been concentrated in developing flow diagrams and routines to handle the five basic subdivisions of computing required for a spacecraft computer. These routines are: Sequencing, RF Alert, Executive Control, Parity

Error, and Compute. The sequencing routine has been developed to accommodate events with variable degrees of resolution (e.g., seconds, minutes, hours, etc.) in either a sequential list or random search for the next event. The RF alert routine is a first priority routine to accept commands issued through the command link. Parity error is a rollback routine which is second in priority to the RF alert. It attempts to correct memory transfer errors which may occur by going back to the last point in the program where sufficient data exists for a restart. The Executive Control is the routine which effects the transfers into and out of the other routines. The compute routine has been developed only to the point of specifying the entry and exit program. It was intended to have typical midcourse correction, orbit transfer, and planetary orbit routines developed by this time, but insufficient manpower precluded this accomplishment.

SEQUENCER DEVELOPMENT

The inhibit core logic sequencer which is being developed under this work unit has been provided with a paper tape system to load the memory with arbitrary information. A sense amplifier design has been developed and will be tested in the next period with worst noise memory content. Various ways have been studied to implement the logic required but no method has been selected.

MAGNETIC CORE FLUX SWITCHING MODELS

Stanford Research Institute has developed a more refined analytical model for core switching which takes into account the initial spike of elastic switching and the heretofore hidden inelastic switching, which also occurs during the initial spike. The model has been programmed and core switching simulated with various combinations of inductive, resistive, capacitive, and unilateral conductive loads and with step, ramp, and exponential current drive. Comparison with experimental data indicated agreement to better than 1% in many cases. The principal disagreement cause is the model of the unilateral conductor (diode) utilized. This work is being supported under Contract 951383 which was entered into on September 7, 1965 for the amount of $55,098, which is a continuation of Contract 950943. The final report, Flux Switching in Multipath Cores, by D. Nitzan and V. Hesterman, under Contract 950943, was received in July 1965 and distributed to investigators in universities, industry, and Government agencies. The contract with Stanford Research Institute will continue into the first quarter of FY 1967.

GUIDANCE COMPUTER ORGANIZATION
NASA Work Unit 125-17-04-02-55
JPL 325-70401-2-3410

A. Avizienis

OBJECTIVE

The objective of this unit is to develop designs of reliable spacecraft guidance computers for unmanned space vehicles with missions of one year and longer. Techniques of fault masking, error diagnosis, and self-repair are being developed and applied to achieve this objective.

SELF-REPAIRING GUIDANCE COMPUTER

The detailed logic design of a diagnosable arithmetic processor has been completed and the fabrication of a breadboard model is about 70% complete. Test procedures for the checkout of the processor have been defined and the test equipment has been designed. Methods for the detection of control faults are being investigated.

Output voltage level measurements have been taken for a representative sample of the integrated circuits that are used in the arithmetic processor. Circuit performance will be evaluated by periodically repeating the measurements during the operational life of the breadboard arithmetic processor.

The system block diagram for the entire self-testing and -repairing guidance domputer has been developed and the logic design of the central (hard core) checking and control unit has been initiated. Besides the arithmetic processor and the central control unit, the system contains an index arithmetic processor, a program (read-only) memory with replaceable peripheral electronics, a "scratch-pad" random-access memory (duplicated), and input/output buffer registers. The study of system program requirements for this guidance computer has been initiated.

A research and development contract with Stanford Research Institute for a feasibility study on a reliable magnetic connection switch received final approvals on September 7, 1965. Phase I of the work is now in progress, and several technical discussions were held with the contractor's project engineer. The switch will be employed to perform the replacement of faulty subsystems of the self-repairing guidance computer.

MODULAR REDUNDANCY

The subcontract for the building of a portion of the redundant sequencer completed procurement requirements during November and has been started. The purpose of this subcontract has been mentioned in several earlier progress reports and will not be repeated here.

The previous report stated that the dynamic synthesis program would be coded for a computer during the present reporting period. No work has been accomplished on this task because higher priority work (both project and advanced development) has prevented assignment of personnel.

OTHER WORK

A visit was made to the Westinghouse Company in Baltimore to discuss their progress in the NASA Headquarters funded study of failure free systems. An extension of this contract was negotiated by Headquarters effective September 29, 1965. Because of delays in assigning people (the contract was interrupted after termination of a previous phase in late FY 1965), discussions were confined to proposed methods of accomplishing the work. It should be noted that a part of the contract, concerned with documentation of a computer program developed during the previous phase, was in active progress and almost completed at the time of the visit.

Visits were made to the NASA ERC and to the MIT Instrumentation Laboratory to exchange information in efforts related to the objectives of this work unit.

PUBLICATIONS

Avizienis, A., "A Study of the Effectiveness of Fault-Detecting Codes for Binary Arithmetic," JPL TR 32-711, September 1, 1965.

Avizienis, A., "Reliability Techniques for Spacecraft Computer Systems," JPL SPS 37-35, Vol. IV, October 31, 1965.

GUIDANCE STUDIES FOR FUTURE MISSIONS
NASA Work Unit 125-17-05-01-55
JPL 325-70301-1-3430

G. D. Pace

OBJECTIVE

The long-range objectives of this work unit are to determine the guidance requirements of future lunar and planetary missions. This includes developing functional descriptions of guidance system configurations to meet the requirements and comparatively analyzing system performance for the alternate candidate system configurations.

ORBIT INSERTION GUIDANCE

A computer program has been developed (and documented in a JPL internal document) to study the maneuver required to insert a spacecraft into an orbit about a planet. This program is a result of a series of programs (described in JPL internal documents) that studies various options of orbit insertion guidance.

The program considers coplanar transfers between an approach hyperbolic trajectory and an elliptical orbit about a planet. The desired transfer may be selected from the numerous maneuver options available including: (1) minimizing the required transfer velocity increment, (2) fixing the size and orientation of the final ellipse, (3) constraining the maneuver to one inertial direction, and (4) constraining the maneuver to a fixed velocity increment. The progrm considers only impulsive maneuvers (i.e. , the velocity increment is added instantaneously).

The accuracy to which the final elliptical orbit may be established can be observed when errors are introduced in the computation and execution of the transfer maneuver. These errors are due to orbit determination uncertainties and maneuver direction and magnitude control errors. The program may be operated in three accuracy modes. In the first, a "grid" mode, the final orbits for all combinations of the error sources are tabulated. The second, a "worst-case" mode, computes the extreme values, both high and low, of the elements of the final orbit for various combinations of the errors. The third, a "Monte Carlo" mode, computes the probability density and distribution functions of the elements of the final orbit based on sampling the various random errors according to their probability density.

This program has found use in studying the orbit insertion guidance requirements for Voyager, and will be used for studies of future missions requiring orbit insertion guidance.

DEORBIT GUIDANCE

A program is being developed to study the maneuver required to deflect a capsule from an elliptical orbit about a planet to an orbit which impacts the planet. Much of the work performed for the orbit insertion guidance program described above has been incorporated in this program, and thus, the programs are similar in operation.

The program computes the desired maneuver velocity vector for the capsule based on various maneuver and atmospheric entry constraints. Dispersions in entry location, velocity, angle, and time and the geometry at entry between the capsule and a spacecraft remaining in orbit about the planet are computed for errors in maneuver location, magnitude, and direction.

Preliminary results indicate that when the capsule is released from orbit the entry location, velocity, and angle are relatively insensitive to the error sources in comparison to the sensitivity when the capsule is released from a hyperbolic approach trajectory. Thus, deorbit guidance may be desirable when accurate control of the entry parameters is required.

This program has found use in studying the deorbit guidance requirements for Voyager, and will be used in studying future missions where deorbit guidance appears desirable.

FUTURE ACTIVITIES

Future work planned includes linking the deorbit guidance program described above with programs to compute the motion of a capsule through an atmosphere so that overall landing dispersions may be studied. Some entry programs have been developed in the past, but additional work will be required to link these programs together for guidance studies.

In addition, study of the guidance system configurations for an active soft lander is planned. Preliminary work was accomplished in a JPL Advanced Technology Study, but considerably more work is needed to establish the guidance requirements, choose possible system configurations, and comparatively analyze system performance.

MANEUVER STRATEGY AND NAVIGATION ANALYSIS
NASA Work Unit 125-17-05-02-55
JPL 325-70701-2-3120
W. G. Melbourne

OBJECTIVE

The objective is to conduct navigation and maneuver strategy analyses associated with advanced lunar and interplanetary trajectories.

LUNAR APPROACH GUIDANCE

A continuation of this study reported in the previous progress report (JPL TM 33-243) involves a simulation of the lunar approach phase for a typical lunar mission using a dynamic filtering approach suggested in Ref. 1. In this simulation an initial set of actual and estimated errors in the state variables are selected from specified initial covariance matrices. At specified points along the approach trajectory, measurements are simulated which serve to update the estimate of the orbit. At a prespecified time, a simulated corrective approach-maneuver based on the latest estimate of the trajectory may be performed to reduce the terminal dispersions. continued tracking after this point is then used to reduce the uncertainty in the estimation of the orbit.

The results of a number of these simulations will show the effect of measurement errors on the orbit estimation and the effects of an approach maneuver on the estimation of the subsequent orbit. In addition the influence of different flight times on the approach orbit estimation will also be studied.

A future modification of the program will allow the application of a terminal or retro-maneuver in order to simulate an orbiter mission.

Efforts are underway to extend the results of Ref. 2, and to apply them to an Apollo type of mission.

NAVIGATION STUDIES

During this period, effort was concentrated on the basic estimation theory as well as on the computer programs which implement the theory of continuous estimation as applied to the Orbit Determination Program (a JPL internal document on the application of the continuous sequential estimation technique to some orbit determination problems was produced).

1. "On the Solution of Covariance Difference Equation by Means of Linear Decomposition and z-Transform," was submitted to Transactions of Automatic Control IEEE for publication in April 1966 as a correspondence note.

2. "On the Covariance Equation in Continuous Estimation Problems," Space Program Summary 37-36, Vol. IV, December 1965.

3. "On the A Priori Information in Sequential Estimation Problems," presented at the National Electronics Conference, October 25-27, 1965, Chicago. This paper was also submitted to Transactions of Automatic Control for publication in April 1966 as a regular paper.

The computer programs under study are:

1. "Continuous Estimation Program used for Orbit Determination of the Low-Thrusted Space Probe," RFP 312-452, August 1965 (7094)

2. J. Michel, "The Continuously-Estimated Orbit Used for Radio Approach Guidance, Earth-Based (COURAGE)," RFP 312-437, July 1965 (7094)

3. "Radio Approach Guidance via Taylor Series Expansion Method," (1620) TM is to be submitted in future.

PLANETARY APPROACH GUIDANCE

A study of orbit determination accuracy during the approach phase of a planetary mission was completed. Some interesting and important conclusions were reached about the effect of a priori uncertainty and noise level upon the estimate, and the observability of the system was studied. Numerical results for a large number (over 300) Voyager type of trajectories were obtained.

A study has been initiated to analyze the effect of numerical errors on orbit determination statistics. Some preliminary results have been obtained.

REFERENCES

1. Solloway, C. B., "Elements of the Theory of Orbit Determination," JPL EPD 255.

2. Pfeiffer, C. G., "A Dynamic Programming Analysis of Multiple Guidance Corrections of a Trajectory," AIAA Journal, Vol. 3, No. 9, September 1965.

CONTROL SYSTEMS (125-19)

APPLICATION OF DIGITAL TECHNIQUES

NASA Work Unit 125-19-03-02-55
JPL 325-90401-2-3440
G. E. Fleischer
E. H. Kopf

OBJECTIVE

In this study the ways in which digital techniques can be advantageously used in attitude control, autopilot, and other spacecraft control systems is being investigated. Methods of successful application, the advantages and disadvantages, and new devices necessary for such systems are being studied. Two areas are currently being investigated. The first is that of digital filtering techniques in spacecraft control systems, and the second is a study of various techniques of pointing high-gain spacecraft antennas.

DIGITAL FILTERING

Sequential least-squares filtering and estimation is a new technique that allows one to smooth noisy measurements made on a linear or nonlinear system and/or estimate variables which can not be measured directly. This technique is quite sophisticated in that to obtain the filter/estimator equations, optimum control theory is applied to the problem, and a set of ordinary differential equations are obtained, These equations are converted into partial differential equations through invariant imbedding, and an approximate solution is found. The result is a mathematical description for the filter/estimator.

As one might expect this filter/estimator is extremely complicated and usually requires a digital computer, rather than conventional hardware, for realization. Because of this complexity one might consider the technique to have little value, but this view is not correct as illustrated by the following examples.

In a recent Advanced Technical Studies - Voyager Soft Landing Study, a propulsive descent scheme was considered. In this system the desired value of deceleration was computed from measurements derived from a radar system similar to the radar and doppler velocity sensor (RADVS) used on Surveyor. These measurements are known to be noisy and thus the computed deceleration is also noisy. Since the deceleration is so critical in a soft lander, it was decided to smooth the computed value by filtering. The sequential least squares filter was determined for this situation and, as expected, it was quite complicated. In this case, however, the filter equations could be simplified, using engineering judgement, to the point where realization could be effected using moderately simple digital hardware.

Further work in this area will be undertaken in the last half of FY 1966.

ANTENNA POINTING

The problem of spacecraft high-gain antenna pointing appears well suited for application of digital control methods. Advantages accruing from stepper motor actuators include their low power consumption and relative simplicity. Given that such a discrete antenna positioning system might be desirable, a detailed examination of stored program and/or ground-programmed pointing control, in possible combination with RF or optical sensing, is required and has been initiated.

Digital antenna pointing system study areas include the evaluation of (1) relative pointing accuracy vs system complexity, (2) pointing program errors due to trajectory variations (selected Mars and Jupiter transfers) and their possible correction by ground command, (3) various methods of calibration to eliminate antenna structural and boresighting errors and (4) requirements imposed by pointing programs and command logic on the central computer and sequencer.

Information generated in the Voyager antenna pointing studies is being utilized as a starting point for this investigation. Results generated in this current study will augment the Voyager studies as well as provide a background or basis for other missions being considered.

ATTITUDE CONTROL OPTIMIZATION

NASA Work Unit 125-19-04-01-55
JPL 325-90501-2-3440

A. E. Cherniack
B. M. Dobrotin
E. H. Kopf

OBJECTIVE

Attitude control optimization studies were undertaken to develop advanced systems, to indicate new components requiring development, to support advanced technical study efforts, and to develop new analytical techniques for attitude control system analysis. The objectives for the current year are to establish the limitations of the analytical techniques that have been developed and to apply these techniques to the synthesis of advanced control systems. The applications include both spacecraft and capsule attitude control systems.

OPTIMIZATION STUDIES

The optimization studies are being conducted both in-house and on a contracted basis. The contract work is with the Purdue Research Foundation and calls for the development of practical optimization techniques and the application of these techniques to the attitude control acquisition problem. Due to the loss of a number of the contract personnel at the end of the 1965 spring semester, that portion of the contract concerned with the application of the optimization techniques developed by Purdue was brought in-house. The term of the contract was extended, at no increase in cost, for six months to permit time for Purdue to introduce new personnel. Discussions are in progress with Purdue to determine areas of mutual interest.

The study of worst-case initial conditions with respect to a performance index for a fairly general class of control system has been accomplished. The results indicated that for linear systems with quadratic indices of performance, the worst-case initial conditions occurred on the boundary of the allowable initial condition space. For nonlinear systems with nonquadratic indices, worst-case initial condition points may occur internal to the initial condition space and must be obtained by the solution of a two-point boundary value problem. These results are significant in reducing the magnitude of the search for worst-case initial conditions and they permit the control to be optimized for these conditions. With respect to the attitude control problem this technique will reduce the effort necessary to answer such questions as: "What angular rate and position initial conditions will result in the longest acquisition time?"

The JPL in-house effort is devoted to the application of the optimization techniques previously developed at Purdue to the attitude control acquisition problem. At present the technique of sequential state estimation is being applied to determine the extent to which the missing state variables in the assumed configuration can be generated. The question asked is: "Are gyros a mathematical necessity for Sun acquisition or commanded turns or is rate information available from Sun sensor signals?" This is a question of observability in a nonlinear system about which theory tells nothing. To get a "practical" determination of this observability an estimator is used where the inputs are the Sun sensor signals. The estimator outputs are the predicted rates. To date it has been determined that for linear Sun sensors accurate rate information is definitely available. Other types of Sun sensors are currently being studied. Following this phase, the techniques of specific optimal control, differential approximation, and approximation in policy space will be applied to optimizing the control.

SPIN STABILIZATION

Work on spin stabilization has been proceeding in two areas. First, the application of an active control system to a spinning body was investigated using rigid body assumptions. The purpose of this investigation was to develop mechanization and stability criteria for a control system which would precess the spacecraft spin axis to an arbitrary position in space. A general method of analysis has been developed which will indicate both stability and performance characteristics. Several computer programs have been developed for both the analog and digital computers. Using these programs, several mechanizations have been developed which will be satisfactory for spacecraft use. See JPL SPS 37-34 and 37-35 for further details of this work.

Future work on spin stabilization will be directed toward a comparison of spin versus conventional stabilization techniques. Various subjects to be considered will include configuration constraints, control sub-system weights, and complexity and pointing accuracy.

The second area of interest is that of considering the spacecraft as a nonrigid dissipative body. A technical report is in the process of being published (JPL TR 32-860). The previous spin stabilization work has considered the spacecraft as a rigid body while in fact the spacecraft is flexible. The report discusses the effects of elasticity from three different approaches. The first two consist of the energy sink method and the discrete damper approach. The third, which received extensive attention uses the normal modes of vibration and the associated damping. This approach seems to be the most realistic. No further efforts are planned in this area.

LIMITED ANGLE ELECTRO-MECHANICAL ACTUATOR DEVELOPMENT

NASA Work Unit 125-19-05-02-55
JPL 325-90301-2-3440

E. F. Koch

OBJECTIVE

The objective under this task is to investigate various limited angle torsional actuators that will tolerate the space environment. The work has been broken into two parts:

1. To modify an existing rotary solenoid by mounting it in a sealed housing.

2. To study the design of a rotary torquer possibly using flexural bearings. This type will not require sealing.

PROGRESS

Due to funding and manpower limitations, this effort was scheduled to begin as of the third quarter of the fiscal year. However, manpower has been provided by this task for the study of a cooperative JPL-GSFC effort to test a hydrogen diffusion microthruster developed under a Headquarters contract. As a result, a new task (125-19-05-03) has been submitted for headquarters approval.

FUTURE ACTIVITIES

During the next report period work statements defining the technical requirement will be prepared. Procurement activity will be started. An investigation will be initiated for the study of a limited angle digital encoder that can be used in conjunction with either of the torsional actuators being considered.

COMMUNICATIONS (125-21)

COMBINATORIAL COMMUNICATION RESEARCH

NASA Work Unit 125-21-01-01-55
JPL 325-10701-1-3310

Edward C. Posner

OBJECTIVE

The objective of this advanced research work unit is to provide a fund of new mathematical and statistical theories and techniques for use in DSN communications systems and to push these methods to the point where they can be picked up by the companion work unit (Information Processing, 350-10900-X-3310, NASA 150-22-11-09-55).

PROGRESS

Combinatorial Coding Research

A demonstration was given (Ref. 1) that 18th power residue difference sets, and hence the pseudo-noise sequences corresponding to them, do not exist. The concept of two-level autocorrelation sequence was generalized (Ref. 2); it was shown that the two-level sequences are the best possible ones that exist. Some questions in error-distributing codes were finally settled (Ref. 3 and 4). A 116 x 116 Hadamard Matrix was discovered, the first one of that size ever found, settling a very famous problem in the subject (Ref. 5). The Hadamard Matrices of order 20 were classified completely (Ref. 6).

Finite-State Machine Research

The theory of "algorithimic complexity" of finite state machines was extended and applied to such devices as the JPL ranging system, which was shown to have minimal complexity for the task to be performed (Ref. 7, 8, and 9). The theory was for the first time extended to lines of digital modules having limited fan-out as well as limited fan-in.

Probabilistic Communication Research

The performance of nonbinary orthogonal phase-modulated codes was theoretically predicted (Ref. 10). The "information-generating function" of a probability distribution was defined and found in some special cases (Ref. 11). The concept of "probabilistic metric space" and its "epsilon-delta entropy" was introduced and some basic results proved; this concept allows efficiencies of data compression systems to be found (Ref. 12 and 13). A theory of run-length encoding was developed (Ref. 1 and 4), which relate to efficient transmission of experimental outcomes.

PLANS

Work on sequences will continue, with particular relevance to Hadamard matrices, difference sets, and error-distribution codes. Algorithmic complexity will be further pursued to find the best upper and lower bounds possible for the complexity of machines to do given jobs. The theory of epsilon-delta entropy for data compression will be pursued, and the entropy of Gaussian stochastic processes studied. The proper method of compressing their functions will be found. These efforts will continue into FY 1967.

CONTRACT

Contract 951076, with the University of Southern California (Electrical Engineering Department), was monitored under this work unit (written under FY 1965 work unit 350-22301-2-3310, NASA 150-22-05-02). Contractor reported progress, as provided for in the contract, in JPL SPS (Ref. 9, 10, and 13). A requisition was written to extend the contract for another year at the same rate of effort. The requisition has been approved by the JPL offices required, and a request for proposal has gone out from JPL procurement to the contractor.

PARTICIPATION

A talk on epsilon-delta entropy was given to the Los Angeles Section of the IEEE Information Theory Group (Ref. 15). A talk was given on combinatorial analysis to a group of high school students at the Museum of Science and Industry (Ref. 16). NASA Goddard SFC was visited to discuss JPL work on the theory of data compression (Posner, October 1). A talk was given on combinatorial communication research at Rockefeller University (17). A visit was made to Stanford University, Mathematics Department, to discuss analytic techniques (Rodemich, October 23).

REFERENCES

1. Baumert, L. P., "The Non-Existence of 18th Power Residue Difference Sets," JPL SPS 37-34, Vol. IV, pp. 264-268.

2. McEliece, R. J., "A Generalization of Two-Level Autocorrelation," JPL SPS 37-35, Vol. IV (also submitted to Canadian Journal of Math).

3. Taylor, H., "A Useful Partition for Rook Domains," JPL SPS 37-35, Vol. IV.

4. Rodemich, E., "A Problem on Rook Domains," JPL SPS 37-36, Vol. IV.

5. Baumert, L. D., "Hadamard Matrices of Order 116 and 232," JPL SPS 37-35, Vol. IV, submitted to Bull. Amer. Math. Soc.).

6. Hall, M. Jr,* "Hadamard Matrices of Order 20," JPL TR 32-761, November 1965.

7. Stanley, R., "New Results on Algorithmic Complexity," JPL SPS 37-34, Vol. IV, pp. 298-305.

8. Stanley, R., "Complexity of (p, q, r) Automata," JPL SPS 37-35, Vol. IV.

9. Stanley, R., "Algorithmic Compexity with Limited Fan-Out," JPL SPS 37-36, Vol. IV.

* CIT Consultant

10. Reed, I. S.†, and R. A. Scholtz,† "N-Orthogonal Phase-Modulated Codes," JPL SPS 37-34, Vol. IV, pp. 255-264.

11. Golomb, S. W.,† "The Information-Generating Function of a Probability Distribution," JPL SPS 37-34, Vol. IV, pp. 288-292.

12. Posner, E. C., and Howard Rumsey Jr., "Probabilistic Metric Spaces and Data Compression," JPL SPS 37-34, Vol. IV, pp. 292-296.

13. Posner, E. C., and H. Rumsey Jr., "Probabilistic Metric Spaces of Infinite Entropy," SPS 37-31, Vol. IV.

14. Golomb, S. W.,† "Run-Length Encoding," JPL SPS 37-36, Vol. IV.

15. Posner, E. C., "Probabilistic Metric Spaces and Data Compression" (talk), October 20, 1965, IEEE Inf. Theory Gp., L. A. Chap.

16. Posner, E. C., "Combinatorial Analysis" (talk), August 3, 1965, Mus. Sci. Indust. Summer Science Series.

17. Posner, E. C., "Recent Research in Space Communication Mathematics" (talk), Rockefeller University Math Department, October 5, 1965.

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† USC Contract

LARGE SPACECRAFT ANTENNA STUDIES
NASA Work Unit 125-21-02-02-55
JPL 325-11001-2-3360

This work unit consists of an analytical study and an antenna structure study.

ANALYTICAL STUDY – R. M. Dickinson

Objective

The objectives of the analytical portion of the Large-Aperture Antenna Study are to obtain design parameters to be used in maximizing the gain-to-weight ratio of erectile antennas and to calculate the gain of large-aperture antennas.

Reflector Surface Equation Development

In carrying out the latter objective, surface equations were derived for erectile reflectors consisting of a flexible reflecting material pulled uniformly between purely radial ribs. The derivation was published in the JPL SPS 37-35, Vol. IV, pp. 273-278, October 1965. The surface equations are to be part of a computer program for calculating antenna gain.

S-Band Serrodyne System

Work on the former objective consisted of completing the design and ordering approximately $9, 000 worth of equipment for construction of a serrodyne phase measuring system. The system will be used to record phase patterns of primary feeds used to illuminate large aperture erectile antennas. A primary feed has been received to be used for experimental measurements and to provide input data for the computer program for calculating gain.

Study Program Rescheduling

From late September to the end of this reporting period, no work was accomplished on the analytical portion of this study due to a 100%time commitment to the *Surveyor* critical data recorder (CDR) study. However, the CDR study is nearly complete and work will resume on the antenna study in January 1966.

The revised large-aperture study schedule will concentrate on completing the computer program for calculating gain and also construction of the serrodyne system for the remainder of this fiscal year.

ERECTILE ANTENNA STUDY – P. W. Cramer

Objective

The objective of this phase of the Large-Spacecraft Antenna Task is to have Goodyear Aerospace Company make modifications to an erectible antenna that they had originally developed under JPL Purchase Order 950467. These modifications were required as a result of tests made on the original antenna. The goals of the follow-on contract, Purchase Order 950905, were to improve the antenna contour accuracy, improve the reflection efficiency of the antenna screen reflecting surface, cut down weight, integrate feed, other mechanical improvements and considerable testing.

Progress

The activity during the first and second quarter of FY 1966 consisted of the manufacturing phase of the program. It was during this period that the folding ribs were replaced with tapered ribs and the invar reflecting screen was replaced with tin plated copper. New sector locks to keep the ribs extended were added.

The technique that was developed to improve the contour accuracy of the mesh surface between the supporting ribs utilized tiedown wires. These wires run from the backside of the ribs to the center of the fabric to pull the surface down as illustrated in the Fig. 1. Considerable time was spent adjusting these wires *so* that the whole surface of the antenna would fall within the required antenna tolerances.

The modifications were completed in November 1965. Since then, the antennas surface has been accurately measured and the antenna put through several cycles of folding and unfolding. After the unfolding, surface measurements were repeated. It was found that after reopening, portions of the antenna surface were out of tolerance with the surface slowly creeping to the original value. A decision by Goodyear was made to increase the load on the main rib extension cable from 125 to 150 lb. With the additional load, the surface reached a stable point.

However, the surface accuracy still was not as good as that desired. Goodyear is now adjusting the location of the antenna ribs and screen tiedowns, and they plan to use additional tiedowns to bring the surface into tolerance.

During the third quarter Goodyear will be continuing their contour accuracy measurement and will perform electrical measurements. It is expected that the contract will be completed during the third quarter.

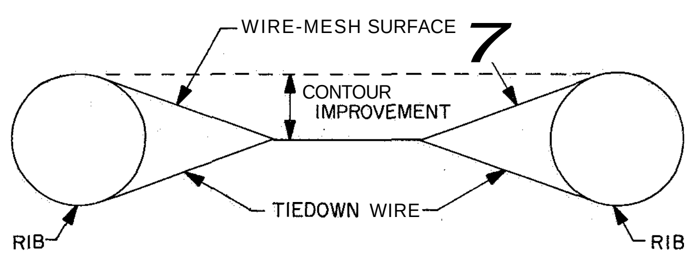

Fig. 1. Use of tiedown wires for improvement of antenna contour accuracy

MODULATION AND DETECTION THEORY

NASA Work Unit 125-21-02-03-55
JPL 325-10601-1-3310

R. Tausworthe

OBJECTIVE

The objective of this work unit is to provide basic and exploratory research of possible future benefit to space communications, such as threshold behavior of phase-locked loops, synchronization, sequential decoding methods, self-acquirable codes, and partially coherent telemetry systems,

THRESHOLD OF PHASE-LOCKED LOOPS

A method for predicting threshold performance of phase-locked devices has been found. It is an approximate method which predicts phase error to within 0.05 radian at a level of 1 radian of phase noise (measured). Another method, based on approximate solutions to the Fokker-Planck equation looks promising, but as yet complete results are unevaluated. A paper presenting the first method will be given at the 1966 National Telemetering Conference in Boston during April 1966.

SYNCHRONIZATION

Maximum sweep rates to acquire lock in phase-locked loops has been investigated as a function of loop damping. The maximum rate for which lock-on is guaranteed occurs when the loop damping $\zeta = 0.707$.

Data synchronization using a signal-squaring-loop has been investigated to determine the optimal presquaring filter. The form of the filter is now known but simplifications to easily realizable cases remains. It also remains to compute the degradation this method affords compared to optimality. If degradation is only slight, the ease with which squaring loops are implementable may prove a dominant factor in system design.

DECODING METHODS

Koerner's (JPL SPS 37-17) method for iterative decoding of the first-order Reed-Muller codes has been extended to arbitrary Kronecker-Product codes with a similar result. However, it seems that the Reed-Muller codes are still the most efficient codes to decode iteratively.

Bounds on sequential decoding capability indicate that rates higher than that now possible with no-coding or moderate block-coding scheme are possible. But it remains to find specific efficient codes and decoding algorithms. Preparations have been made to simulate such a convolution-coded/sequential-decoded communications system by digital computers to evaluate encodings and decodings. A particularly simple decoding algorithm has been discovered, but how the computer complexity compares with Fano's method is not yet known for the particular code size useful in space communications.

Evaluation of code-detection degradation due to partially incoherent detection of code words has been evaluated for one- and two-way links. For two-way links, it appears that there is an irreducible probability of error for which no increase in ST_b/N_0 is advantageous. This irreducible P_E need not occur on one-way systems, if properly implemented. However, there is in each mode a proper way to choose modulation indices, and these have been tabulated.

INTERPLANETARY PROPAGATION STUDIES
NASA Work Unit 125-21-02-04-55
JPL 325-10801-2-3310
D. Muhleman

OBJECTIVE

The objective of this task is the detailed investigation of all factors that affect radar and radio measurements in the interplanetary medium. These include general relativity, atmospheric and ionospheric propagation, and propagation in the solar corona. The results of this effort are utilized in the obtaining of more precise astronomical constants as well as in the improvement of the DSIF communications capability within the interplanetary medium.

PROGRESS

Theoretical studies of the effects of the medium on the propogation of S-band signals was continued throughout this period. The phenomena studied include the following media: the Earth's troposphere and ionosphere, the solar corona (electron plasma), and the solar gravitational field. Applications to planetary radar astronomy were carried out for purposes of planning experiments. Radio tracking data from the Ranger series was utilized in a study of the troposphere and ionosphere. Calculations of expected effects on the Mariner IV S-band signal as the spacecraft passes behind the solar corona were computed as an aid in making the forthcoming measurements.

The propagation studies were reported in a number of places during this period. The mathematical developments were presented in a paper "Theoretical Studies of Planetary Radar Signals Passing Near the Sun" by P. E. Reichley and D. O. Muhleman at the 1965 fall URSI meeting at Dartmouth College. Some of the results from the Ranger data as well as a discussion of future observational plans were presented in a paper "Atmosphere and Interplanetary Refraction Effects on High-Precision Planetary Radar Measurements" by D. O. Muhleman and P. E. Reichley at the Tenth AGARD, Ionospheric Research Committee Meeting in Rome, Italy, September, 1965.

Further research on the problem has been published in two additional papers: "Radar Signals in Model Atmospheres" by P. E. Reichley and D. O. Muhleman, JPL SPS 37-35, Vol. IV, and "A-Priori Statistics on Differential Corrections" by P. E. Reichley, JPL SPS 37-35, Vol. IV. The later paper deals with the mathematical difficulties associated with the proper separation of the propagation effects from practical radio observations during the orbit determination process,

Work on the interpretation of radar planetary echo data in terms of the planets' surface roughness and surface materials was continued. Studies of the surface roughness of Venus and Mercury from JPL radar observations were published in a paper "Radar Scattering from Venus and Mercury at 12.5 cm." by D. O. Muhleman in Radio Science, NBS, December 1965. The primary results presented in this paper include the quantitative comparison of the surface roughness of Venus relative to the Moon (Venus is far smoother) and extensions of theoretical ideas concerning reflections from rough surfaces.

NEW CIRCUIT ELEMENTS RESEARCH
NASA Work Unit 125-21-03-04-55
JPL 325-10901-1-3330

C. T. Stelzried

OBJECTIVE

The objective of this task is to investigate millimeter wave components and techniques to ascertain the future applicability of this frequency range to space communications and tracking. This involves the development of instrumentation for sccurate determination of insertion loss, VSWR, power and equivalent noise temperatures of passive elements. Millimeter wave circuit elements are being evaluated in a radio telescope system consisting of a 60-in. antenna and a superheterodyne radiometer (SPS 37-33, Vol. IV). The radio telescope was used to observe the 90-Gc temperature of the Moon during the December 30, 1963 eclipse (JPL SPS 37-26, Vol. IV, p. 181) and the most recent eclipse, December 18, 1964. These experiments were joint efforts by personnel from JPL and the Electrical Engineering Department of the University of Southern California.

OBSERVATIONS AND DATA REDUCTION

90-Gc radiometric observations of the sub-Earth point on the Moon were carried out daily during the period August 3 to September 12 (JPL SPS 37-35, Vol. IV). Due to atmospheric attenuation the measured radiometric temperature is a function of elevation angle. A data reduction method using a least-squares best fit technique was presented (JPL SPS 37-28, Vol. IV, p. 148) which involved taking logarithms of the equations relating the measured temperatures to the actual Moon temperature as a function of elevation angles. This was necessary in order to linearize the equations. However, an unknown weighting factor was introduced (Ref. 1, p. 247) due to taking the logarithms. A new data reduction method has been made (SPS 37-36, Vol. IV) using the least-squares best-fit technique in which linearization is achieved by using the first-order correction term obtained from a Taylor expansion (Ref. 1, p. 256). All measurements are equally weighted with this technique. A comprehensive analysis of the 90-Gc radiometric data from the August 3 to September 12 daily measurements and from the December 1964 eclipse are being performed under the University of Southern California (USC) Subcontract 951004 and will be included in the Contract Final Report.

A new Subcontract 951424 was entered into on October 19, 1965 with USC for continuation of the "Study Program of Millimeter Wave Radiometry for Radio Astronomy."

General technology in mm wave radiometry will continue to be studied. Mixers and low-noise amplifiers will be investigated theoretically as well as experimentally.

REFERENCE

1. Worthing, A. G., and Geffner, J., Treatment of Experimental Data, John Wiley and Sons, New York, 1960.

TRACKING AND DATA ACQUISITION (125-22)

PLANETARY PROPAGATION STUDY

NASA Work Unit 125-22-01-01-55
JPL 325-20201-2-3360

R. M. Dickinson

OBJECTIVE

The objective of this study is to provide antenna engineers with information as to the magnitude of the effects of planetary or lunar proximity, envelopment or coating, and burial or immersion on landed antenna patterns and impedance.

STUDY INTERRUPTION

This study was interrupted due to a 100% time commitment to the Surveyor critical data recorder (CDR) study. The CDR study is now essentially complete and work should resume on the propagation study in January 1966.

Nevertheless, some work was done on a literature search for information on extraterrestrial body reflection coefficient data and for techniques of investigating scattering of electromagnetic waves.

REVISED STUDY PROGRAM

The study program has been rescheduled to concentrate on developing a computer program for calculating the effect of multipath propagation on the pattern of a landed capsule antenna. A report of this phase of the study is scheduled for publication at the end of this fiscal year.

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MULTIPACTING AND IONIZATION BREAKDOWN STUDIES
NASA Work Unit 125-22-01-02-55
JPL 325-20501-2-3360
R. Woo

OBJECTIVE

To conduct voltage breakdown studies to obtain information helpful in avoiding voltage breakdown in RF components designed for space applications.

ANALYTICAL STUDY

Analytical studies on the similarity principle for multipacting have been completed. It was found that the boundary of the multipacting region can generally be broken down into two separate boundaries. The first boundary is the phase-controlled boundary and the scaling relations dictate that the rf and dc voltages are proportional to $(fl)^2$, where f is the frequency of the rf voltage and l the characteristic length of the electrode configuration. The second boundary is the minimum energy boundary and the rf and dc voltages are proportional to fl.

A paper entitled "A Similarity Principle for Multipacting Discharges" by Drs. R. Woo and A. Ishimaru of the University of Washington was written. It covered all the results of our scaling studies and was presented at the Eighteenth Annual Gaseous Electronics Conference, sponsored by the American Physical Society and held in Minneapolis, Minnesota, October 20-22, 1965. The abstract will be published in the Bulletin of the American Physical Societv. The complete paper is being prepared for submission for publication to the Journal of Applied Physics. Some results have also been reported in JPL SPS 37-35, Vol. IV.

Our computer program written to numerically integrate the normalized differential equation describing the electron motion between coaxial electrodes was used to check any correlation between multipacting in the parallel plates and the coaxial cases. As expected, the correlation was very good when the b/a ratio (b is the diameter of the outer electrode and a is the diameter of the inner electrode) was small. However, the deviation increased quite considerably for b/a ratios greater than 4 and in the cases run, the deviation was so great for a b/a ratio of 15 that the mechanism responsible for multipacting in the parallel plates case was no longer possible in the coaxial case. The results however, for the parallel plates analysis, may be used in studies of multipacting in 50-ohm transmission line components since the b/a ratio is approximately 2. 3.

EXPERIMENTAL STUDY

It has been suspected that the pressure within a mated type-N coaxial connector is not the same as ambient pressure. Exact pressure levels need to be known since the breakdown mechanism is dependent on pressure. Therefore, pressure monitoring tests were run with mated N coaxial connectors using a strain gage and an alphatron gage. The male type N connector has a rubber gasket against which the female connector rests when the connectors are mated. It was shown that in a vacuum environment with and without this rubber gasket, the differences in the pressure-vs-time profile of the interior of the mated connectors were very significant. So effective are the sealing effects of this rubber gasket that while the ambient pressure is 10^{-4} - 10^{-5} mm Hg outside the connector, the interior of the mated connector may be around 1 mm Hg. Since ionization breakdown occurs in the pressure range of 1 mm Hg and multipacting in pressures lower than 10^{-3} mm Hg, ionization rather than multipacting would be the dominant breakdown mechanism. In our experiments it was shown that three 0.093 in.-diameter vent holes in the mated connectors provided sufficient venting so that the interior pressure was the same as ambient pressure.

With sufficient venting provided, some voltage breakdown experiments were run with type N connectors at 10^{-6} mm Hg pressure and 960 mHz frequency. No sustained breakdowns were observed. However, occasional 'spike' breakdowns were observed at the highest rf power levels (100 w). It is suspected that the spike nature can be attributed to the change in surface characteristics. This will have to be examined more carefully when more rf power becomes available at this frequency.

It is planned to run some breakdown experiments with rigid coaxial line segments. Pressure levels will be better controlled and more meaningful data obtained. Pressure windows employing teflon in a mechanical seal have been designed for the experimental setup and fabrication will start.

Coaxial multipacting experiments below 100 mHz originally planned for an outside procurement will be performed in-house. We have found some difficulty in locating a rf source to provide sufficiently high voltage levels across the coaxial electrodes to be tested. A proper source is being procured.

Procurement of a 1-kw VHF source is now in process. The award of the contract is planned for the third quarter of FY 1966.

VOLTAGE BREAKDOWN FACILITY

The Voltage Breakdown Facility now under construction will be used to perform ionization and multipaction breakdown measurements on radiating structures such as antennas.

During this reporting period, the building that will house the facility is about 70% complete with all the walls, basement, and roof finished. A completion date in February 1966 is expected.

The plastic vacuum chamber had been held up pending location of a vendor that can supply plastic sheets large enough for fabricating the 6-ft chamber. A source has been found, and estimates are now being received from several fabricators.

All mechanical equipment (pumps, valves, piping, and adaptors) have been received.

The procurement package for the screen room lining for the inside of the facility is 90% complete.

It is planned to have the facility operational the first part of FY 1967.

QUANTUM ELECTRONICS RESEARCH

NASA Work Unit 125-22-02-01-55
JPL 325-20101-1-3330

W. H. Wells

OBJECTIVE

The objectives of this task are to analytically and experimentally investigate the potential of coherent optics in deep space communication and tracking and to achieve basic advances in quantum electronics.

FEASIBILITY OF OPTICAL SPACE COMMUNICATIONS AND TRACKING

A continued revision of our analytical studies of this topic indicates further advantage for a system operating at a wavelength of 10.6μ. Revision is based upon reports in the open literature regarding improved efficiency and power output of the N_2-CO_2 laser which oscillates at this wavelength. Efficiencies as high as 15% have been reported, and power outputs exceed 100 w. The unfocused beam from this laser readily burns sticks and clothing, and will heat an asbestos sheet to incandescence so rapidly that the sheet can be used as an image converter in a lighted room to follow motions of the beam.

Under the restrictive conditions discussed in the last semi-annual report, this wavelength may offer a several decibel advantage (relative to the microwave region) for communication from deep space to ground, or, for very long range planning, potential improvement as high as 20 db using an orbiting relay station.

We successfully built and operated a N_2-CO_2 laser and are continuing to buy and build infrared components for research at or near the 10.6-μ wavelength, including a cryogenic detector system using mercury doped germanium, and more parts for N_2-CO_2 lasers. Our plans for using infrared equipment are changed somewhat. We are now planning a laboratory model of a low noise optical communication system, and postponing atmospheric wavefront distortion experiments until most other questions of feasibility have been answered. There are three reasons for changed emphasis. First, preliminary block diagrams for a low-noise 10.6-p receiver raise questions to be answered in the laboratory, especially problems associated with the very restricted tuning range of a N_2-CO_2 laser. Second, literature reviews and discussions regarding astronomical site surveys, light propagation in a turbulent medium, etc., suggest that any site we could choose that is reasonably accessible to our laboratory would not be typical of a site that would be useful for an operational optical communication system. Third, we expect that better satellite targets will be available in the future for lidar (light radar) ranging to test the system over a path that includes the upper atmosphere.

We have almost completed a computer program that simulates atmospheric effects upon a certain type of optical receiver which would employ a laser preamplifier. In this case the signal-to-noise ratio depends upon the intensity of light in the focal point, rather than in the total power, and in principle, we could dissect the image and use only the most intense portions (the position of which changes rapidly with conditions in the atmospheric path). Therefore, we studied the statistics of peak intensity.

A study contract with Perkin-Elmer Corporation for $80,000 to study unconventional telescope configurations for optical space communication is in the final stages of the procurement process and will become active in January 1966.

FAR-INFRARED MASER

A proposal for a far-infrared maser was published in the Journal of Applied Physics, Vol. 36, pp. 2838, September 1965. The molecular beam apparatus for testing the proposal is essentially complete. Preliminary tests will occupy the months to follow. The weak point in the apparatus design is probably the molecular beam intensity that reaches the mass spectrometer for detection and analysis. The beam will be greatly attenuated by slits in the electrostatic deflector that will be used to analyze the relative populations of rotational energy levels. Some redesign may prove necessary.

We have successfully fabricated an effuser (molecular beam nozzle) by a novel technique that permits the use of soft, corrosion-resistant metals (nickel, in our case). Twelve-mil soft nickel tubing was threaded with hard wire and strung on a device resembling a loom. This held the tubes straight while they were packed together and clamped into a nozzle. One can see through all of the tubes simultaneously in a bundle of 81, even though the tubes are 3 in. long and individually only 0.010 in. in diameter.

The theoretical study of optical modes of a resonator that is suitable for this maser (but not to be included in the first-generation system) was completed. Amplitude and phase distributions for the output were published in JPL SPS 37-35, Vol. IV, pp. 264-266.

ADVANCED SPACECRAFT TRANSMITTERS

NASA Work Unit 125-22-03-01-55

JPL 325-20601-2-3360

L. J. Derr

OBJECTIVE

The objective of this work unit is to advance the state-of-the-art in microwave power amplifiers for spacecraft transmitters.

CATHODE STUDY

The behavior of oxide cathodes in long-life microwave power amplifier tubes is fairly well understood. Because of the high cathode current density required at power levels above a few hundred watts, dispenser cathodes are more likely to be required. There is a need to understand more than is presently known about the behavior of dispenser cathodes operated for long periods.

A long-life dispenser cathode study contract will be initiated in the third quarter of FY 1966. Cathodes and electron guns will be operated and life-tested in a microwave tube like environment. The problems of cathode depletion, poisoning, evaporation, and emission homogeneity will be studied.

DATA HANDLING AND PROCESSING (125-23)

GSE DEVELOPMENT FOR ADVANCED SPACECRAFT

NASA Work Unit 125-23-01-01-55
JPL 325-31501-2-3430
O. E. Linderman

OBJECTIVE

The overall objectives of this GSE development task are to devise more comprehensive GSE testing techniques and other spacecraft tests which will result in a more reliably operating spacecraft. Circuit testing techniques which will predict incipient failure of a spacecraft piece part or component are being evaluated. The following testing techniques are currently being investigated: (1) margin test techniques for GSE and spacecraft equipment, (2) RF noise spectra, and (3) infrared measurements of the various circuits.

These various testing techniques are being evaluated using a digital test circuit which cycles through a short operational routine. Individual circuit cards as well as the complete system are being used in the evaluation study. Measurements are also being made on several spacecraft Central Computer and Sequencer (CC&S) subsystems.

STATUS

The evaluation of circuit testing techniques was partially suspended during part of the report period to allow repair and modification of the infrared camera and because of a pressing commitment to deliver a memory-oriented CC&S operational support equipment (OSE). The limited amount of manpower available was used to fabricate and deliver the OSE for a Voyager Project advanced CC&S study and development.

A Barnes Engineering infrared camera Model T-4D has been shared with several other development groups. This camera emphasized spatial resolution at the expense of temperature sensitivity, in contrast to the Model 1-8A camera previously used. The work requiring this spatial resolution has been completed and the camera has now been modified to a Model T-4 configuration which yields improved temperature sensitivity. The camera is again in operation and the circuit testing technique evaluation has resumed.

The poor operation of the infrared camera has delayed the accelerated aging phase of the correlation studies since the voltage margin and the RF measurements were completed earlier in the year. The present status of the three testing techniques is as follows.

Voltage Margin Measurements

Voltage margin measurements of the digital test system and of each circuit card were completed earlier this year. These measurements were made in some detail. Various width pulses and pulse amplitudes were used as parameters in determining several voltage margins for each circuit card. Various abnormal operations of the complete system were used in determining the several system voltage margins. Since these earlier measurements the system voltage margin measurements have been repeated (after the recent infrared measurements) to determine if the system is in the same condition as when previously tested. The resulting shmoo diagram agrees very closely with the one reported previously in JPL SPS 37-32, Vol. IV, pp. 52-57.

Circuit Noise Measurements

RF noise spectra were completed earlier this year for the operating system and for each circuit card. As reported earlier these measurements were made in a shielded box and also in a shielded room. RF measurements were also made of the prototype CC&S subsystem at this time. Flight quality CC&S subsystems have not been released by the projects as yet for RF measurements to compare with these earlier RF signatures.

RF measurements of the digital test system have been repeated since completing the infrared measurements. The results agree closely with the graphs previously reported.

Additional RF noise detection test equipment is being considered for possible application. A miniature RF current probe and recording system developed by the Atlantic Research Corp. is being investigated. The Honeywell RF probe instrument Model UG 1983 A1 has been ordered. This instrument resulted from their use of an RF receiver to detect the RF radiation generated by intermittent component failures. This RF probe will be used to supplement the present readings.

Infrared Measurements

Very few infrared photos have been taken for this study since the T-4D model infrared camera was delivered to JPL a year ago. The photos were poor and very noisy. Part of the trouble was a damaged detector. The camera has been repaired and modified by the manufacturer, and is now in operation. Calibration curves, taken before the camera was shipped to JPL, indicate a great improvement in temperature sensitivity and a marked reduction in ambient noise level.

The capabilities of the infrared camera were first determined after delivery at JPL and data was taken to use in making operational comparisons in the future. Preliminary measurements indicate the temperature measuring sensitivity is not quite as great as that obtained at the manufacturer's plant. The difference in sensitivity is attributed to different methods of measurement.

The camera warmup temperature characteristic has been determined and the effect of the electronic temperature offset control measured and plotted. The present ambient temperature cycle in room 198-302 has also been plotted.

Reference photos have been completed of each of the 30 circuit cards as it operated in the short routine of the digital test circuit. These photos will be used as a reference for making the future comparisons.

Accelerated Aging Cycle

After collecting the reference data (also repeating voltage margin and RF system measurements) the circuit cards were placed in an environmental oven and cycled for 5 days at temperatures of 32 and 158°F. This is the aging cycle used by the manufacturer to find the infant failures, 6 hr at one temperature and then 6 hr at the second temperature for 5 days. The circuit cards have been returned to the rack and the three different sets of tests are being repeated. The digital test circuit has operated as before and no change has been found in the infrared rest results.

PLANNED ACTIVITIES

The evaluation of the circuit testing techniques to detect incipient failures will continue. The cards will be placed in the chamber and cycled for 5-day periods and retested after each period. Voltage margin, RF noise, and infrared measurements will be made after each aging cycle to detect a drift or change in data. When a change in data is detected, trend analysis and correlation studies will be made. The measurements will first be made of the complete digital system and then of individual cards when the system measurements indicate this change in operation. Thus the analysis will be extended from the system to the circuit cards as well.

There is some question if repeating the infant-mortality temperature cycle will produce an accelerated life test. If the results of several temperature cycles show little change, the circuit cards will be stressed by increasing the voltage above rated.

Voltage margin, RF noise, and infrared measurements will continue on spacecraft subsystems. These measurements will be taken on Ranger flight quality CC&S equipment when this subsystem is released from the Ranger Program. These measurements will then continue during the scheduled life test of the Ranger CC&S.

DIGITAL VIDEO PROCESSING
NASA Work Unit 125-23-02-01-55
JPL 325-30101-2-3184
F. C. Billingsley

OBJECTIVE

The objective of this work unit is the development of methods and techniques for the processing of picture-type information to restore the video information to allow meaningful, quantitative measurements.

DIGITAL COMPUTER

At the end of the last reporting period, funds had been made available from this project and from the Ranger Project for the purchase of a small digital computer to be used in the development of procedures and techniques for digital video processing. The purchase of this computer had long been planned but was previously deferred for budgetary reasons. At the end of the present reporting period, manufacturers' proposals for this computer have been received and are being evaluated.

VIDEO FILM CONVERTER

The final upgrading of the video film converter has been started. At the close of this reporting period, all of the functional design and a large part of the detail design have been completed, and construction of the necessary hardware begun. In order to minimize downtime of the equipment as much hardware as possible will be built by Link at Palo Alto, and then brought to JPL for installation, This will occur during the next reporting period.

FOCUS MEASURING DEVICE

This is a device which will measure the degree of focus on the cathode ray :ube of the video film converter. A LogEtronics "Focatron" with a special probe mounted in the VFC film plane has been purchased for this purpose. Although we ıave not yet become adept at using it, our tests to date indicate that it will satisfy ;he requirement.

SAMMA-CONTROLLED FILM PROCESSING STUDY

Due to continued lack of available manpower and funds, this study was not ›ursued during the present reporting period. The need for this processing has not lecreased, however, and the study will be begun as soon as the necessary funds :an be made available.

ƆPTICAL PROCESSING

Due primarily to lack of manpower and available funds, we have been unable o begin the study of optical video data processing techniques. It is desired that the ;tudy begin with the analysis of the cathode ray tube recording system, and with the ›ossibility of applying spatial frequency filtering to the video pictures. This study would then be expanded to cover other coherent and incoherent light processing techniques. The sooner this work can begin, the greater will be its usefulness to the digital video processing activity. However, since presently available manpower cannot be diverted to this task, the addition of one engineer competent in the field of modern optics is required if this is to be accomplished.

VIDEO DATA COMPRESSION

As a result of the previous contacts we have had with the Lockheed Missiles & Space Co., we received during this period an unsolicited proposal from them for a study of the reduction of noise effects on the compression of video data. Although this work is of general interest, it was decided it was not properly supported as a part of this task.

SPS ENTRIES

The times of impact of RA VIII and RA IX have been determined from the video data to within ±25 microsec. This was done in conjunction with the Ranger Project, and is reported in JPL SPS No. 37-35.

SYMPOSIA

F. C. Billingsley presented a paper at the Society of Photographic Instrumentation Engineers (SPIE), Tenth Technical Symposium, August 1965, in San Francisco. The title was "Processing the Ranger and Mariner Photographs and Other Digital Video Data at the Jet Propulsion Laboratory." In addition, he was invited to present a paper at the Data Reduction and Computer Working Group of IRIG dinner meeting in October 1965. The title of that paper was "Mariner-Mars 1964 Television."

OTHER REPORTS

The group has done considerable study on various areas of video recording, and reports on the following three are being prepared:

1. Signal-to-Noise Transfer Through the Film Process. This study is concerned with the signal-to-noise ratio at various parts of the nonlinear film processing involved in the original reduction of video data to film, and the subsequent film-to-film printing process.

2. Spatial Frequency Response with Cathode Ray Tube Recording. New derivations of the effect of various shaped cathode ray tube spots on the obtainable spatial frequency response have been developed, and compared with actual typical CRT results.

3. Loss of High Frequency Resolutions due to Jitter in CRT Recording. The effect of synchronization jitter or accumulated time base error due to tape machine wow and flutter causes a reduction in the effective high frequency response of a recording system.

The performance of the Ampex FR-1400 Analog Tape Machine has been studied to determine its suitability for the Surveyor Project and the conditions under which it should be operated. (A JPL internal document details this work.) Further work is continuing, and will be reported during the next reporting period.

CONSULTATION

Personnel assigned to digital video system task are contributing in a consulting category to the technical direction of the SCTV TDHS. Thus, much knowledge derived in the digital video system activity is applied to direct flight support.

Personnel of the group have acted as consultants to Dr. Naugle of the Manned Space Flight Center in Houston. He is concerned with the digital reduction of the lunar orbiter pictures for Apollo purposes, and wishes to utilize our hardware and programming techniques, wherever they are applicable.

The group has also been approached by Dr. Sanders of Space-General Corporation to assist in their work with Goddard Space Flight Center concerning Trias and Nimbus pictures. The effort involved is the digitizing of certain Trias and Nimbus pictures and the subsequent conversion of processed pictures to high-quality film.

VIDEO MODULATION TECHNIQUES
NASA Work Unit 125-23-02-03-55
JPL 325-30301-2-3340

G. L. Fultz

OBJECTIVE

The objective of this task is to develop and evaluate techniques for compressing slow-scan television data and coding it for transmission over interplanetary distances. This effort is intended to establish a broad theoretical base from which specific feasibility studies can be pursued and laboratory verification undertaken.

TELEVISION DATA COMPRESSION STUDY

In late July 1965, an in-house study was undertaken to examine the interrelationships between the various television data processing functions and their effect on a scientific digital television mission employing data compression. The realm of data processing functions considered is from analog-to-digital conversion in the spacecraft to picture reconstruction on the ground. The two data compression algorithms chosen for the study represent some of the simpler element-to-element techniques known. These algorithms are used only as a vehicle for associating the various television data processing functions on the total television mission success and not necessarily as a recommended method to be incorporated into a spacecraft system.

The ground rules for this study are:

1. A scientific digital television mission is the fundamental assertion. Thus, the data compression algorithm considered should be basically information preserving and not take advantage of the psychophysical properties of the picture interpreters, as would, for example, the Robert's pseudo-random-noise technique.

2. Only simple data compression algorithms that operate on an element-to-element basis will be considered. Thus, line-to-line and area techniques are excluded from this study.

3. The realization that the constraint of the choice imposed by item 2 will probably not result in a system to be recommended for implementation on an actual spacecraft.

4. In all cases considered, line synchronization is assumed to be known. However, a discussion will be presented concerning the problems associated with synchronizing variable length lines of data.

5. The synchronization procedure for coding of element positional information should cause as little data expansion as possible for highly nonredundant pictures. The coded element positional information should be chosen with a particular reconstruction procedure capable of operation on noise corrupted data.

6. The spacecraft television system to be used as a vehicle for study will be of the Mariner IV type with a raster of 200 by 200 elements.

The experimental results for the study are obtained by computer simulation on an IBM 7094. The total television data compression study includes the following:

1. Investigation of four TV data compression algorithms.
2. Coding of positional information.
3. Derivation of gross and net data compression ratios.
4. Effects of sensor noise on the TV data compression algorithms and on picture fidelity.
5. Effect of bit errors caused by the noisy communication channel on the reconstruction and display of television data.
6. The interplay of various data compression algorithms and ground processing functions (i.e., contracts enhancement, brightness scaling, addition of calibration information) on the total television mission success.
7. Spacecraft TV data storage and compression algorithm implementation procedures.

To date, the following results have been obtained.

1. The sensor noise for the Mariner IV television system has been experimentally determined.
2. Data compression ratios for the Mariner IV television pictures and for a few selected Ranger IX pictures placed in the Mariner format have been obtained.
3. Reproduced compressed Mariner IV and Ranger IX photographs have been obtained. Two Mariner IV picture number 11's (Fig. 1a and 1b) and two Ranger IX (Fig. 1c and 1d) compressed photographs are included in this report. Figure 1a corresponds to the zero-order prediction algorithm with an aperture of one, and Fig. 1b corresponds to the zero-order interpolator algorithm with an aperture of two. Both pictures have had the brightness data stretched by a factor of four and thus any perturbation caused by the compression algorithms on the data are magnified by a factor of four. Figure 1b shows severe contouring effects due to the picture compression algorithm and subsequent brightness scaling. Results of processing the Ranger IX pictures were more promising. Figure 1c corresponds to the zero-order prediction algorithm with an aperture of one and Fig. 1d corresponds to the zero-order interpolator algorithm with an aperture of four. Contouring began to show up only when the aperture was widened by a factor of two to three as compared to the Mariner IV picture 11.

This is due to the fact that the Ranger IX pictures represent a more active information source.

The gross and net compression ratios for these four pictures are contained in the following table.

Picture	Compression Ratio	
	Gross	Net
A	2.56	1.70
B	5.25	3.50
C	1.25	0.84
D	4.23	2.82

In one instance, the net compression ratio was less than one. This means that more bits were required to specify the compressed picture than the normal 6-bit PCM picture without data compression. The low net compression ratio of 0.84 was due to a large amount of positional information required for this picture.

SDS 930 COMPUTER - VIDEO MODULATION TEST CONSOLE INTERFACE

The SDS 930 computer system less line printer was delivered to JPL on September 9, and became operational on September 13. For the Video Task, the 930 computer will be used as a simulator tied directly to the video modulation test console (VMTC). The computer will be programmed to simulate spacecraft television data handling and data compression transfer functions, the noisy communication channel, and the ground demodulation, detection, and data reconstruction functions.

Figure 2 shows the proposed interfacing between the VMTC and the 930 computer which is now being designed. The EJ30 junction box and D/A converters are being procured from SDS. The system should be operational by mid-May 1966.

VOYAGER

During the preliminary design phase for Voyager, there have been discussions concerning whether to use an analog or a digital TV relay link for the Voyager capsule-bus high rate communication system. About a week and a half was spent analyzing the problems associated with an analog TV relay link. The results of this study are contained in a JPL internal memorandum on the Voyager capsule TV relay link. It was concluded that a digital TV relay link should be the preferred approach for the Voyager high rate capsule communication system. Even though an analog TV link may be more efficient for short communication distances, the problems associated with transforming the analog information in the bus to digital data, and the associated reconstruction and synchronization procedures on the ground appear

(1)nebulous in definition in many instances, and (2) difficult to analyze and predict performance. In addition, AD effort has not been pursued in these areas as yet.

SYMPOSIUM REPORT

The Fall Joint Computer Conference, held at the Convention Center in Las Vegas, was attended November 30 to December 2. The major emphasis of the conference was placed upon time-sharing, programming languages, and the impact of computers on society,

SPACE PROGRAM SUMMARY

A paper entitled "The Effect of Sensor Noise on Quantization Accuracy During Analog-to-Digital-Conversion" was submitted to JPL SPS 37-36, Vol. IV.

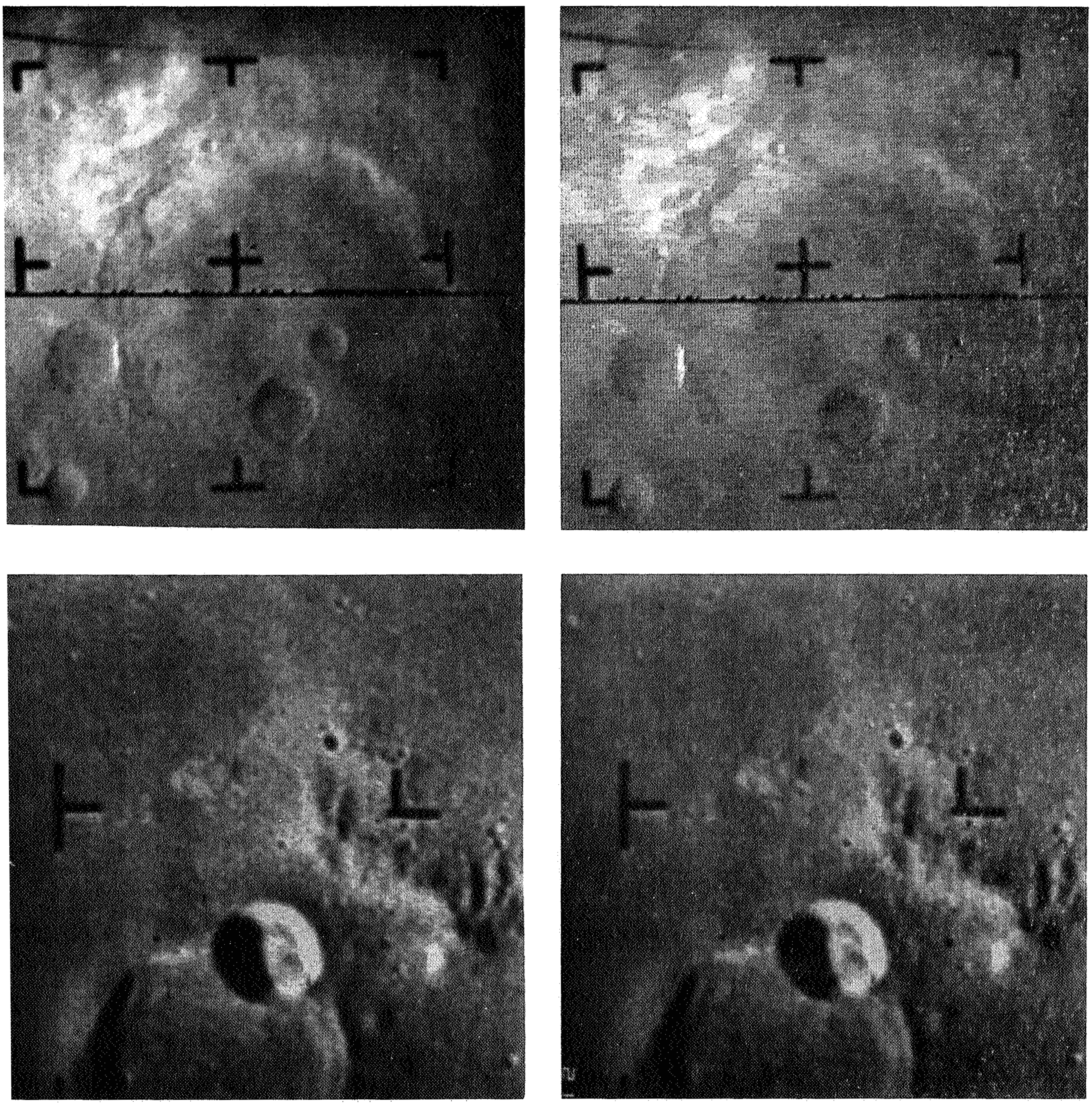

Fig. 1. Compressed Mariner IV and Ranger IX photographs

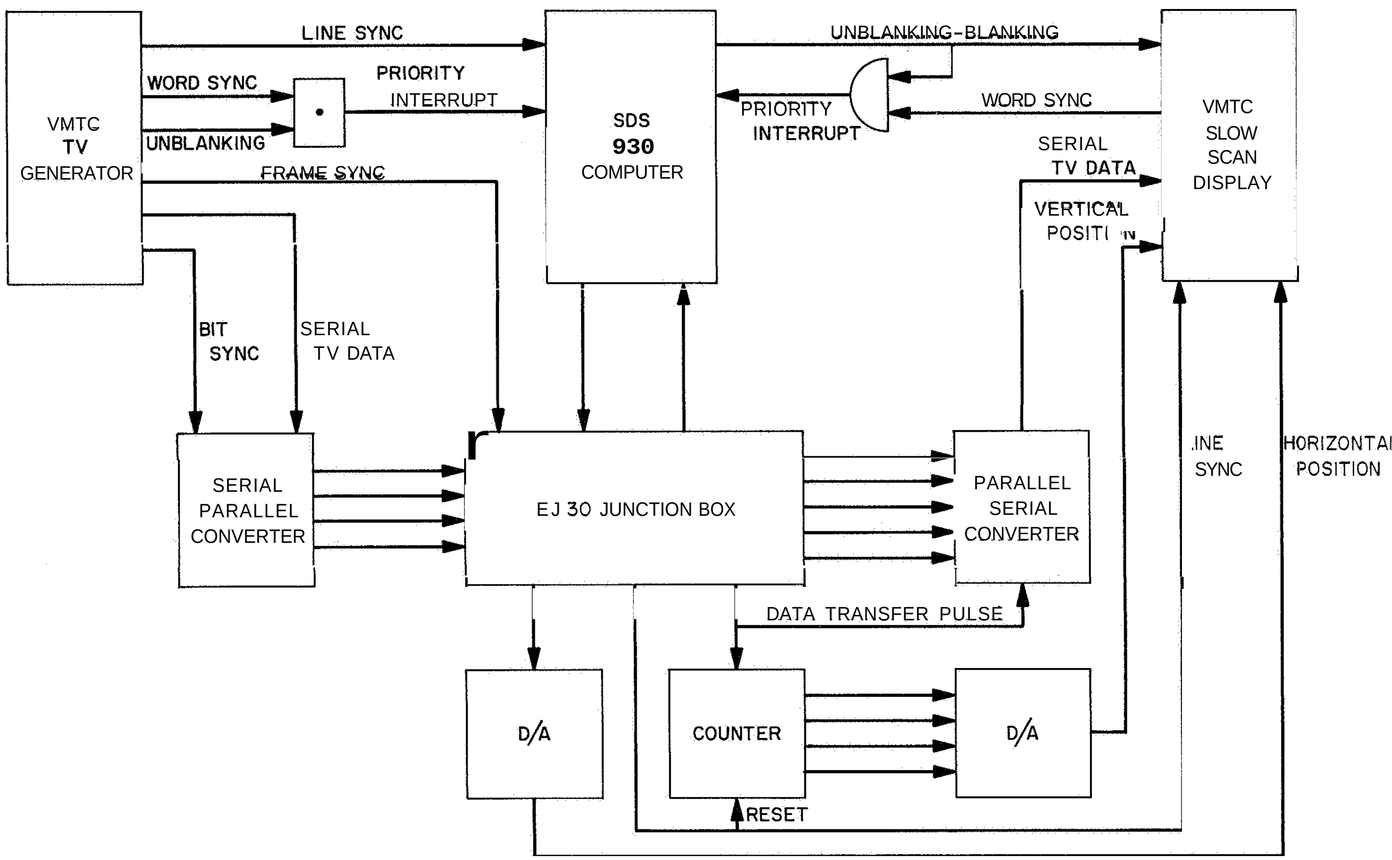

Fig. 2. SDS 930 computer and VMTC interface

ADVANCED DIGITAL BULK MEMORY SYSTEM DEVELOPMENT
NASA Work Unit 125-23-02-04-55
JPL 325-30401-2-3340
W. Clement

OBJECTIVE

The objective of this work unit is to investigate the feasibility and the development of large-capacity ($10^6 - 10^{10}$ bits) bulk data storage systems capable of replacing conventional tape recorders for specific applications on future NASA spacecraft.

HELICAL TAPE PACK TRANSPORT STUDY

Objective

The objective of this subtask is to determine the feasibility of handling and storing tape in a helical pack configuration. This technique, if feasible, could provide storage capacities of 10^9 to 10^{10} bits in a considerably smaller volume than possible with conventional reeling techniques.

Activities During Report Period

CPFF Contract Number 951348 was awarded to Kinelogic Corporation on August 6, 1965, for the development of a helical tape transport. A tape-forming machine has been designed and fabricated from which helical tape has been formed from existing commercially available tape with no degradation to the Mylar backing. Post-form heat curing of the helical tape has resulted in extremely uniform packs. However, cracking of the oxide coating due to the forming process was evident with some tapes. On the other hand, some tapes using a thermoplastic binder such as Memorex 62L have showed no degradation due to the forming process. Unfortunately, tapes using such binders normally have a comparatively low temperature capability.

The design of a breadboard transport capable of accommodating helical tape was completed and parts ordered for fabrication purposes. The present design employs two cylindrical drums to accommodate the helical tape. The tape is transferred from one drum to the other at each of the ends.

Future Activities Planned

The contract completion date is March 6, 1966. A helical tape transport breadboard should be fabricated and evaluated both experimentally and analytically at that time.

MISCELLANEOUS BULK DATA STORAGE STUDIES

Objective

The objective of this subtask is to continuously monitor and evaluate a number of bulk storage configurations and techniques for possible use in advanced spacecraft data handling systems. Electron beam, laser beam, and nonlaser optical techniques being actively pursued by industry are included under this subtask.

Activities During Report Period

Trips were made to both North American and Ampex to discuss the present status of laser beam recording. Further activity has been delayed due to inadequate manpower availability.

Future Activities Planned

No specific plans are presently being made in this area for the next six months due to the lack of available manpower.

VIDEO DATA RETRIEVAL

NASA Work Unit 125-23-02-09-55
JPL 325-30901-2-3240
R. Nathan

OBJECTIVE

This task is aimed at maximizing the effectiveness of photographic observations performed by spacecraft devices within the constraints of flight equipment implementation and the capacity of the spacecraft-to-Earth communication channel. It is anticipated that studies of the information content of pictures from successfully completed Ranger and Mariner missions will reveal the amount and nature of the real information in these pictures - as opposed to that which is redundant. Based upon this knowledge, methods for extracting such information and describing it succinctly are to be defined so that the communication efficiency can be raised with the result that the greatest amount of retrievable real information will become available for picture regeneration from spacecraft observation.

Current, short-term objectives include continuation of video data processing technique development in which information enhancement and correction are used to raise the visual significance of this data. Design and construction of hardware to facilitate such processes as image correlation, for pattern recognition, will be undertaken to augment the more conventional facilities of the Video Data Retrieval Laboratory.

ACCOMPLISHMENTS

The unique immediacy of the video data processing facility, comprising the Section 324 digital computer (Digital Equipment Corp. PDP-7) and the Video Data Retrieval Laboratory, made possible real time pictorial display of Mariner TV pictures of Mars as the data was received at JPL from the DSN.

Required software and interface hardware were started on May 3, 1965 and completed prior to receipt of initial data on July 15, 1965.

Subsequent to termination of the real time operation, during receipt of Picture 4, additional nonreal time video processing was undertaken.

Whereas real time processing was limited to contrast enhancement, the nonreal time processing included removal of TV camera shading and edge enhancement, or image sharpening.

During development of nonreal time processing methods a procedure for shading correction based solely upon use of received data was evolved.

Figure 1 shows Picture 9 in raw form, except for removal of transmission anomalies, with a small area fully processed. Effectiveness of the techniques employed may be inferred from the visible information content of the insert relative to the remainder of the picture.

SUMMARY

The Mars TV processing effort was active from May 3 to September 27, 1965.

During this period approximately three thousand words of computer program were written and debugged to implement the various techniques developed.

A total of 1,239 hr of machine time was expended, largely in production of some fifteen hundred differently processed hard-copies (photographs) of the Martian surface.

A succession of progressively more critical screenings has resulted in a final file of approximately three-hundred prints of the twenty-two Mars pictures, system calibration pictures, and a few other pictures of significance to the project.

A formal JPL Technical Report Describing the development and application of these computer processing techniques to both *Ranger* and *Mariner* pictures is being written and will be published in early 1966.

CONCLUSION

Consideration of the process of development of general techniques and suitable operating programs, as well as selection of process sequences and parameters applicable to each discrete case, will immediately reveal that this task could not have been accomplished except in a closed-loop mode with direct access-through the computer console-to the operating programs in conjunction with immediate and continuous display of the effect of each phase of the process.

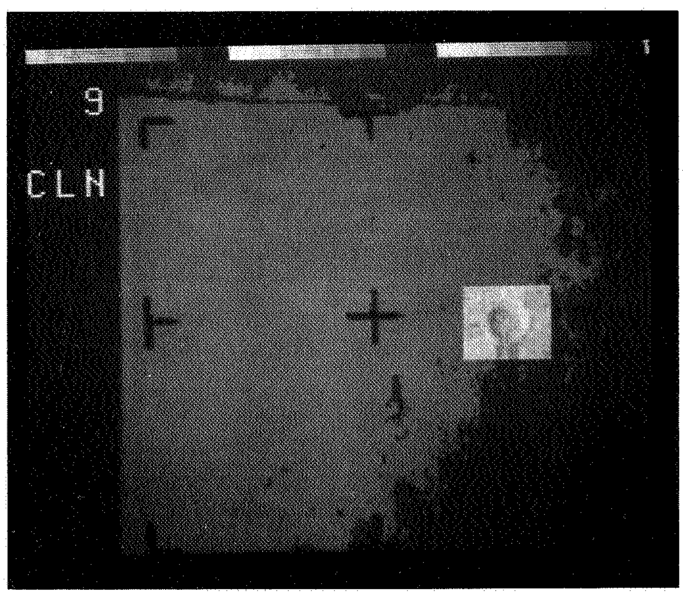

Fig. 1. Raw form of Picture 9

SOLID-STATE STORAGE SYSTEM

NASA Work Unit 125-23-02-14-55
JPL 325-31401-2-3240

R. H. Nixon

OBJECTIVE

To develop a memory system design capability that would satisfy a variety of mission-independent spacecraft applications. State-of-the-art memory system techniques will be explored and developed. Storage capabilities up to 10^5 bits will be considered.

STATUS

As a result of JPL's XFP 7246 a decision has been made to award a study contract to Univac, St. Paul, for further development of their Mated-Film memory element[1]. The Mated-Film memory element has been developed at Univac for DRO (destructive readout) applications in high-speed commercial computers. This proposed contract will sponsor the development of the memory element for NDRO (nondestructive readout), low-power, low-speed, spacecraft type of data handling applications. The development can be considered an optimization of parameters for spacecraft applications.

The estimated cost of the contract is $100,000 and its duration approximately 9 months. The contract will receive partial funding support from NASA Work Unit 186-58-06-07 since a special report on the sterilizability of the memory element is required. Award of the contract is estimated for the third quarter of FY 1966. The contract will be incrementally funded and will require approximately $50,000 during FY 1967.

[1]The Mated-Film element is a magnetic memory device which consists of two layers of thin film which sandwich an insulated sense line. The operation of the pair is similar in many respects to a single planar film. That is, both of the elements have uniaxial anisotropy (an easy or preferred direction of magnetization) and the switching mechanism is operated by rotation of the magnetization vector rather than by magnetic domain wall motion. However, the planar film has an open, or air, return for flux, whereas in the Mated-Film pair, each element provides the flux return path for the other.

SPACECRAFT DATA SYSTEMS RELIABILITY

NASA Work Unit 125-23-02-15-55
JPL 325-31601-2-3340

J. R. Kinkel

OBJECTIVE

The objective of this task is to develop reliability analysis and synthesis techniques which explicitly include reliability measures of success (including partial success or "graceful degradation") to improve the reliability of complex tree-like structures which characterize spacecraft data processing systems.

RELIABLE TIME MULTIPLEXING

The recently published JPL TR 32-828, Reliable Time Multiplexing by Replacement, describes the analysis and computer simulation of an iterative array of logical circuits. The array performs the multiplexing function and is designed to correct component failures within a cell by replacing the entire cell. The simulation demonstrated that the fault correction capability and the usable life of the array were extended as the cellular concept was fully exploited. To simplify the analysis and simulation, switching is performed by electromechanical instead of solid state devices. The high power consumption of this implementation and the recent advances in microelectronics have led to logical design with metal-oxide-silicon field-effect transistors (MOS FET).

MOS FET IMPLEMENTATION

Currently, a model of the MOS FET, which includes the various failure modes of the device, is being refined to permit logical design. Among the characteristics of MOS FET's which may be exploited to direct system behavior upon failure are:

1. The transistor, as a voltage controlled resistor, can monitor and control node voltage in a cell.

2. The gate capacitance can serve as a temporary memory, provide a temporary latch, or indicate the physical condition of the oxide layer.

3. The roles of source and drain may be interchanged since the transistor is a symmetric device.

Simple circuits for which a set of failures will yield a smaller set of outcomes are also under investigation. Substitution of the transistor model into these circuits will permit computer simulation of complex arrays. The development of one array will contribute to the synthesis of other matrix-like data processing functions: multiplexing, addressing, storage, and analog-to-digital conversion.

SHORT COURSE AND CONFERENCE

A two week UCLA course, Linear System Theory - The State Space Approach, was attended August 2-13. The course develops a method for simulating linear systems on a digital computer by first transforming them to finite state automata.

The Switching Circuit Theory and Logical Design Conference (University of Michigan, October 6-8) was attended to become familiar with current developments in automata theory and sequential machines. A portion of the conference dealt with the modular synthesis of finite state machines.

INSTRUMENTATION (125-24)

ELECTRO-OPTICAL SENSOR EVALUATION
NASA Work Unit 125-24-01-03-55
JPL 325-40301-2-3230
L. R. Baker

OBJECTIVE

Imaging system development for lunar and planetary applications requires extensive test and evaluation of image sensor and image system performance in terms of those characteristics which define image quality. The evaluation of these image and optical parameters over the temperature and pressure conditions of space requires the application of specialized techniques and equipments.

It is the purpose of this program to continue the evaluation of the Westinghouse SEC vidicon procured from funds obtained during FY 1965 under NASA Task 125-24-01-03. Parametric evaluations such as (1) the sterilizable vidicon being developed under NASA Task 186-58-06-03, (2) ruggedized imaging system 125-24-01-05, (3) new image sensors, (4) such image sensors as might be requested by other NASA centers, and (5) continued evaluation of image sensors for current space programs such as *Mariner* and *Surveyor*. Additionally, it is thepurpose of the program to upgrade the sensor test set to provide the capability to more adequately evaluate these sensors.

PROGRESS DURING REPORTING PERIOD

A camera head was fabricated for the Westinghouse SEC vidicon to mount the tube and its special focus and deflection yokes and its video preamplifier. Because of the relatively high signal electrode capacitance, it was necessary to construct a special video preamplifier for the SEC tube. When power was initially applied to the SEC vidicon, it was observed that the target current was excessively high. Upon visual examination of the tube, it was discovered that the target had an unexplained tear. The tube was subsequently sent to the manufacturer for evaluation. The tube did operate, but with a very noticeable blemish in the video signal caused by the torn target, The evaluation given for the tear by Westinghouse was a high voltage arc-over between the G5 mesh and the target.

A trip was taken by JPL personnel to Westinghouse to observe the tube operating and record the operating potentials of the tube. The tube that was ruined was purchased as an operable reject to test the setup prior to evaluating the good tube, so a new operable reject was sent to JPL and is now being connected to the test set. The tube should be operating before the end of the reporting period. After initial evaluation of the setup, the good SEC tube will be connected to the test set and evaluated. This evaluation should be completed by the end of February. The test procedures are in rough draft form and will be completed by mid-January.

Trips were taken by additional JPL personnel for the purpose of performing an evaluation of the status of low-light image sensors throughout industry. This work was done in support of the Voyager imaging system proposal submitted to NASA by the Space Sciences Division of JPL. Keeping up to date on current developments is an important part of this task.

An RFQ has been submitted to industry for an environmentalized camera head to test one-inch vidicons. The camera head will be used in conjunction with the TV camera tube test set, and will consist of a housing for a video preamp, the image sensor, and the magnetic deflection and focus yokes. The camera head will be designed to operate over the range of -50 to +150°C at 10^{-7} torr, and test all types of one-inch vidicons, i.e., all magnetic, all electrostatic, and all combinations. The bids were due by the end of December, with delivery scheduled 90 days after go-ahead. Most of the firms queried replied with a "no bid." Additional RFQs will be sent to other vendors.

A brief test was run on two image orthicon tubes to test procedures to be used on the SEC tube. The sensitivity of the image orthicon is about the same as the SEC tube. The camera used was a GE airborne image orthicon camera, and the tubes tested were GE type 7409 and GE type 7806. A transfer characteristic was run on each tube to see what problems may be encountered for evaluating low-light image sensors. The quality of the video from the camera was quite poor, and further evaluation of the other tube parameters was not considered profitable.

A scan converter was purchased to improve the slow scan testing capability of the test set. Slow-scan TV monitors are expensive, difficult to use, and very difficult to observe, especially when evaluating an image sensor for image quality. The scan converter converts the slow-scan video from the image sensor to standard TV rates, where the video is displayed on a standard "Conrac" TV monitor. Thus, the subjective evaluation of the image sensor will be much simpler and effective for operation of slow-scan rates.

During the reporting period, seven vidicons for the Surveyor program were tested. A complete spectral response was run on these tubes from 400 to 670 μ wavelength.

These vidicons are then shipped back to Hughes for use in flight hardware

PLANS FOR NEXT REPORTING PERIOD

The WX5419 SEC vidicon will have been tested and evaluated. The contract for environmentalized camera head will have been let and the completed unit received and checked out.

RUGGEDIZED IMAGING SYSTEM DEVELOPMENT

NASA Work Unit 125-24-01-05-55
JPL 325-40501-2-3230

L. R. Baker

OBJECTIVE

The state-of-the-art technology in vidicon cameras for space applications has yet to yield a small lightweight, reliable vidicon camera incorporating microelectronics capable of withstanding long periods of operation in a lunar or planetary surface environment such as would be encountered in a Surveyor II roving vehicle or Voyager capsule. Therefore, the objective of this program is to design, develop, and fabricate a prototype, miniature, ruggedized vidicon camera capable of operation following exposure to a sterilization and high-impact environment. The vidicon image sensor to be used in this camera is being developed under JPL Contract No. 950985 by RCA Electron Tube Division, the sterilization portion of which is being funded under NASA Work Unit 185-58-06-03-55; JPL Job No. 385-84301-2-3230.

PROGRESS DURING REPORTING PERIOD

Work was delayed on this program until the ceramic vidicon envelope design was completed on Task 186-58-06-03-55 in the second quarter of FY 1966.

At the present time, design studies are under way by Section 356 to study: (1) methods of mounting and holding the image sensor and (2) methods of maintaining a close tolerance interface between the lens and the image sensor. The tube-mounting problems are the primary problems at present and are fundamental to the ruggedization of the camera. These studies are nearly complete, and one approach shall be selected to build and test mounting hardware.

It has been decided to base the camera electronic design on the Mariner IV camera. Circuit design modifications are under way to utilize microcircuits wherever possible and feasible. The camera horizontal line and vertical frame rates will be based on initial Voyager rates to allow experimentation on both microcircuit modifications and Voyager video rates. After circuit modification, the operational breadboard model will be used to build and package a prototype ruggedized imaging system. It is intended to let a contract to do the packaging based on the work done at JPL.

Two severe problems remain to be solved before completion of a ruggedized imaging system. A ruggedized shutter must be fabricated to withstand 3000 g, and a program must be initiated to develop a ruggedized lens to withstand 3000 g. These problems are not impossible to solve but will certainly require funds into FY 1967. During FY 1966, work will begin on the ruggedized shutter, and it is proposed to let a contract during FY 1967 to develop a ruggedized lens.

Figure 1 is the proposed schedule for the remainder of the fiscal year. Additional funds are required in FY 1967 to complete the project.

PLANS FOR NEXT REPORTING PERIOD

The tube mount design study will be complete and a prototype mount fabricated. Work on the ruggedized shutter will have begun and a prototype completed. The camera electronics modifications will be complete and a contract let for packaging the fabrication.

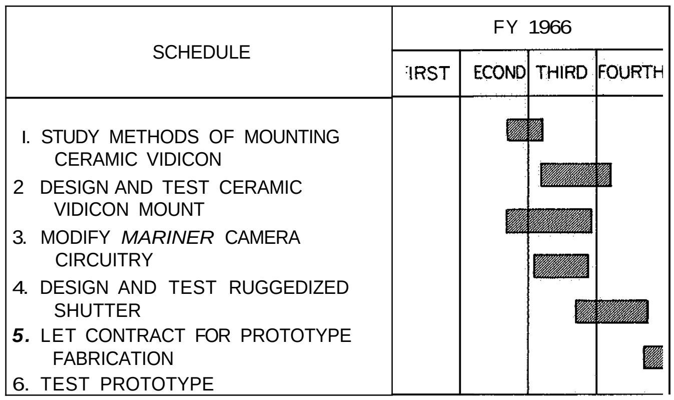

Fig. 1. Ruggedized imaging system development

ADVANCED SIGNAL CONDITIONING ELECTRONICS
NASA Work Unit 125-24-01-08-55
JPL 325-41001-2-3220

H. R. Mertz

OBJECTIVE

The advanced signal conditioning electronics account was used for the development of electronic circuits for Martian atmospheric analysis instrumentation, Primarily, it was used to develop circuits for mass spectrometer and low-concentration water vapor instruments.

ATMOSPHERIC MASS SPECTROMETER

An all solid-state automatic-range switching electrometer using the new metal oxide silicon (MOS) transistors, which had been previously developed, was modified and used to replace the vacuum tube electrometer in a magnetic sector mass spectrometer system. This system, using the solid-state electrometer, was successfully flown aboard a high altitude research aircraft on December 20, 1965.

Magnetic sector mass spectrometers normally use an exponential decay to generate the accelerating voltage that is used to separate the ions. A more desirable accelerating voltage curve is that of an inverse (1/x) function. An effort to generate such a function by digital techniques has been instigated. If this approach proves feasible, it will not only provide the desirable linear mass scale, but will also provide more flexibility in the handling of the mass spectrometer data.

WATER VAPOR CONCENTRATION MEASUREMENT

Electronic circuits have been developed to utilize the water vapor concentration dependence of the impedance of an aluminum oxide detector. Such an instrument could be used to measure the partial pressure of water vapor in a planetary atmosphere. Further evaluation of the circuit is continuing and will culminate in a report upon completion.

INTEGRATED CIRCUITS

An extensive evaluation of the new analog integrated circuits is being initiated to determine their suitability for use in high-quality flight circuits. These circuits offer the possibility of a savings in size and weight for flight instruments.

TEST INSTRUMENT DEVELOPMENT

NASA Work Unit 125-24-03-02-55
JPL 325-40601-2-3710

C. Martin Berdahl
Richard C. Willson

This task includes state-of-the art development work on transducers and instrumentation for measurement of force, pressure, acceleration, and temperature as applied to spacecraft component testing. Status of work done on this task during the first six months of FY 1966 includes the following.

ULTRAVIOLET SENSITIVE MULTICHANNEL SPECTROMETER

The multichannel spectrometer for shock tube gas studies was fabricated. It ɩs an adjustable bandwidth instrument which has the unique capability of simultane- ɔusly sensing and quantitatively measuring energy at five selected wavelengths ɔetween 500 and 8000 A. Operational checks revealed two problem areas. One of hese, the inability to mechanically adjust two channels to the desired wavelength ɔosition, was a design oversight and was soon corrected. The second problem was ;omewhat more serious and took considerable time to overcome. This was a vacuum eak primarily caused by bending of the cover plate. Stiffeners welded to the outside ɔf the plate solved this problem and now the instrument is being set up for calibration ɩsing a glo-discharge type source wherein several gases and gas mixtures may be ɩsed and spectral data obtained for reference.

After calibration the instrument will be moved into the hypersonic shock tube acility where it will be used in the field of planetary entry vehicle studies. Delivery f the instrument to the hypersonic shock tube facility will constitute completion of he project as far as development work is concerned.

'REE FLIGHT TELEMETER FOR HEAT TRANSFER MEASUREMENT

A heat transfer telemeter has been designed to measure heat transfer on wind ɹnnel models in free flight. The telemeter has not yet been flown in the wind tunnel. everal designs have been considered involving a variety of sensors, such as, iermocouples, solid-state temperature sensors, thin film gauges, and thermistors. thin film thermistor on a thin substrate of nickel was found to be best suited for ur needs. The rest were rejected for the following reasons: low output, slow esponse, or construction difficulties. One very small solid-state sensor was found) have the required output and response time; however, the difficulty of attaching a sbstrate and its sensitivity to visible light made it impractical to use.

Since the heat transfer measurement must be made during flight durations of ·om 60 to 140 millisec, the thin film thermistor was selected because it has a more ɩan adequate rise time.

The telemeter is a Colpitts oscillator, miniaturized, and well potted. From ·evious experience with a similar circuit, it is expected to be insensitive to accel- ·ation and temperature change. The convective heat transfer sensor will be a disc nickel 3/8-in. diameter and 0,001-in, thick with the thermistor deposited on one de. These sensors are commercially available. The sensor will provide a feed back variation in the oscillator circuit that will cause a frequency shift corresponding to a temperature change of the thermistor. Calibration will be accomplished in the same manner as a thick film calorimeter.

IMPROVEMENTS TO A MULTIPLE PORT PRESSURE MEASURING SYSTEM

Improvements were made in the port seals of a recently developed ten-unit, twelve port per unit, multiple-port pressure measuring system which enabled it to be used at high pressures as well as the more normally encountered low pressures. This instrument has been recently used in the Propulsion R & D area as well as in the JPL wind tunnels and is proving to be a very useful device.

A technical description of the system by J. M. Kendall, Sr. entitled "120-Pox Multiple-Pressure-Measuring Systems" is being published in JPL SPS 37-36, Vol. IV

RADIATION INSENSITIVE KNUDSEN GAUGE

Work on a radiation insensitive Knudsen gauge for absolute measurement of very low pressures was started in the first half of FY 1966. Due to lack of man-power, this development work has been set aside. It is still felt that the development of such a gauge is of significant importance in the field of vacuum and low pressure measurement to continue should the opportunity present itself. However, little if any work is expected to be done on it during the last half of FY 1966.

PRESSURE TRANSDUCER DEVELOPMENT

NASA Work Unit 125-24-03-03-55
JPL 325-40701-2-3710

R. Steve Rogero

OBJECTIVE

To improve and/or develop sensors and associated instrumentation required for the measurement of high-frequency pressure phenomena encountered in rocket motor performance testing. The adverse environmental conditions encountered necessitates development of thermally insensitive transducers.

Work on this task was concentrated in the following areas during the first half of FY 1966.

SYSTEM FREQUENCY RESPONSE

The frequency response of the instrumentation svstem used to make high frequency rocket engine pressure measurements has been extended from 40 kc to approximately 80 kc, primarily through the use of transducers with natural frequencies in the order-of 400 to 500 kc. The system response is presently at the limit of the tape recorder and efforts to extend this range are in progress.

DYNAMIC TEST EQUIPMENT

Investigations into the desirability of purchasing sinusoidal pressure generating equipment continue. Companies producing such equipment are Princeton University, BB & N, and Standard Controls. At this time, the capability of generating sinusoidal pressures in the range of 100 to 10 kc seems possible.

INTERNAL ROCKET ENGINE TEST PROBE

In an effort to investigate the resonant combustion phenomena internal to the rocket engine (3-dimensionally), a probe was developed. Early tests on the unit have been unsuccessful due to the extreme heat transfer rates present. A new probe utilizing improved cooling methods is being fabricated and will be tested in the near future.

THERMAL PROTECTION OF TRANSDUCERS

Near-flush diaphragm transducers with improved cooling techniques[1] have been evaluated during resonant combustion. Although some degradation of frequency response occurs when cooled adapters are used, the transducer appears to be capable of surviving extended firings with frequency response in the order of 15 to 20 kc.

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[1] Kistler 603A with helium bleed adapter.

OTHER

Preliminary tests using helium as the driver gas in the shock tube in order to more closely simulate actual combustion phenomena have been conducted.

A paper containing much of the information found in JPL TR 32-788 by R. M. Clayton and R. S. Rogero entitled Experimental Measurements on a Rotating Detonation-Like Wave Observed during Liquid Rocket Resonant Combustion, August 15, 1965, was presented at the 7th Liquid Propulsion Symposium, October 19-21 in Denver, Colorado.

Continued liaison with other organizations working in the same field and with transducer manufacturers through visits and technical symposia have been of benefit. Techniques and facilities in use at JPL are not duplicated in other parts of the country and the results of JPL's effort have been of considerable interest to others.

PLANNED ACTIVITIES FOR LAST HALF OF FY 1966

1. Continued evaluation of transducers and cooling techniques with emphasis on models such as the Kistler Helium Bleed Adapter and the recently developed Photocon Semiconductor Transducer.

2. Extension of the recording equipment frequency response through the use of direct record or film techniques.

3. Decision on sinusoidal pressure generating equipment.

4. Continued evaluation and design improvement of three-dimensional probe.

5. Technical Report on techniques and capabilities in use by JPL for evaluating transducers - last quarter FY 1966.

6. Participation in B-88 Subcommittee on Pressure of the ASA Sectional Committee on Calibration of Instruments - next meeting Jan. 17, 1966, Princeton, N.J.

RADIOMETRY INSTRUMENTATION DEVELOPMENT

NASA Work Unit 125-24-03-05-55
JPL 325-40801-2-3710

C. Martin Berdahl
J. M. Kendall Sr.

OBJECTIVE

The objectives of this task are twofold. First is the development of standards, methods, and procedures for measurement of solar simulator performance as related to spacecraft systems and associated components. Second is the development of unique instrumentation for measurement of performance of JPL solar simulators. The first of these objectives is the principal objective receiving the greatest portion of the task effort.

A request for a small absolute radiometer for use in the measurement of total radiation at all incident angles has resulted in a concentration of effort on this particular phase of the task during the first half of FY 1966. Added effort on this task which was donated cooperatively by the requestor has helped us to progress far beyond our expectations and to have at this time a working prototype of the radiometer.

ABSOLUTE RADIOMETER DEVELOPMENT

The element of this absolute radiometer consists of a conical cavity receptor made by winding fine enameled wire of high temperature coefficient of resistance on a silver foil cone thus making the cone isothermal with rapid temperature equalization (Fig. 1). By electronic control, the cone is precisely held at the known temperature of a surrounding thermal guard. Since no heat transfer occurs between cone and guard, the radiation leaving the cone (a known quantity) minus unknown radiation entering the cone must be supplied to the cone electrically. The intensity of unknown radiation is determined from watts supplied heat, aperture area, and cone temperature. To realize full potential accuracy (1% or better) the radiometer must be used in a vacuum of 10^{-5} torr or better, otherwise gaseous conduction and convection spoil accuracy. Greatest intensity measurable with this radiometer is about 0.3 w/cm^2 (0.25 Btu/ft^2-sec).

Performance tests have been made so far in a heated, evacuated chamber and are indicative of absolute measurement ability of the order of 1% or better. Performance tests are continuing and include incident angle sensitivity tests which it is hoped will show a close approach to the cosine curve of sensitivity. Since this is at present in the prototype stage of development the associated electronics is in a similar state and must be cleaned up before an easily operable and reliable measurement system is achieved.

Our plan is to continue to improve and simplify the radiometer design by incorporating some alternative schemes of thermal control and to test the radiometer in various environments including at wavelengths approximating those of solar radiation.

For more information on this radiometer, reference is made to a report by J. M. Kendall, Sr. and J. A. Plamondon entitled "Cavity-Type Absolute Total-Radiation Radiometer" in JPL SPS 37-35 Vol. IV. A technical paper was also presented at the 20th annual Instrument Society of America Conference and exhibit at Los Angeles on October 4-7 1965 by J. M. Kendall Sr.

Another type of absolute radiometer which was developed to a high degree of perfection in the last six months was a circular, edge-guarded, round-flat-plate radiometer sensitive to irradiance in a near-cosine manner in two directions. The unique qualities of this radiometer included a spiral cut thread across its surface to improve absorbance at grazing angles and a bi-filar wound heater element sandwiched in between two thin aluminum plates. The guard was heated with the same current, however the voltage across the central plate was measured separately in order to accurately measure the power required to raise the plate to a certain temperature. If this temperature is equal to the temperature produced by a certain irradiance level then the total irradiance on the plate may be computed. Tests of the plate in a dark, evacuated chamber at various wall temperatures, show a correspondence with calculated values in the order of one percent. Again this transducer is in need of short wavelength calibration.

It is not so much in the absolute sense at present but for intercomparison and testing for characteristic change with life and environment that repeatable solar calibration under known environmental conditions is considered necessary. To satisfy this demand a small environmental chamber of sufficient size for simultaneous calibration of a minimum of three flat-black-plate type of radiometers is being proposed. This chamber is needed as soon as possible in order to properly evaluate the work already done. An appreciable effort will be made to get it started during the last half of FY 1966. We propose that this task provide a modest level of funding in support of this purchase; additional funds would be obtained from other applicable areas (124-09, and possibly flight projects).

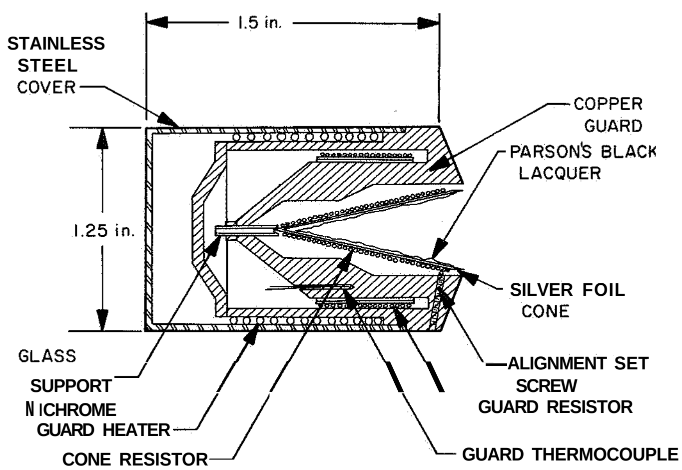


Fig. 1. Sketch of prototype radiometer

IMPROVEMENT OF ELECTRON MICROSCOPE RESOLUTION
NASA Work Unit 125-24-03-06-55
JPL 325-41101-2-3240

R. Nathan

IMPROVEMENT OF ELECTRON MICROSCOPE RESOLUTION

In order to get the desired special dark field images of the organic microscope specimens, it is necessary to install equipment which will intensify weak off-axis images. There does not now exist commercially available equipment to do this intensification. RCA has recently advertised equipment which takes the visible image formed on the viewing phosphor and intensifies that result for closed circuit television viewing. The loss in efficiency caused by the conversion of the electron beam to light by the phosphor is too severe to be of use for this work.

AEI (the manufacturers of the present JPL microscope) had during the last year put on the market an intensifier which used an open ended vidicon tube placed directly in the vacuum column in place of the phosphor screen. They have since withdrawn this $10,000 device from the market because it too did not perform much more efficiently than the RCA system, and customers were disappointed. Discussions with the manufacturer revealed that the image formed on the vidicon selenium layer was being scanned at commercial rates (60 half-frames/sec). It was immediately clear to us that we could use the slow-scan television system used for early Ranger missions as a means of allowing an integration of the image on the phosphor before readout. By means of a scan converter the scanned image can be frozen for display. By scanning once every one to two seconds, it should be possible to increase the amount of effective image intensity almost one hundred times over the original system. Negotiations have been completed with manufacturer to deliver us only that portion of their system necessary to adapt our equipment to theirs. Delivery should be some time in February.

Because of the emphasis on the biosatellite project there has been developed pressure to take over the area where the microscope is presently installed. Negotiations have been essentially completed to move the instrument to the building where other work on video retrieval is taking place. It is intended that the video intensifier equipment be connected to this video retrieval facility, thereby making it possible to take the video data directly into a computer for processing.

ELECTRONICS TECHNIQUES AND COMPONENTS (125-25)

ELECTRONIC PACKAGING ADVANCED DEVELOPMENT
NASA Work Unit 125-25-03-01-55
JPL 325-50101-2-3570

E. R. Bunker

OBJECTIVE

There are five major objectives which support this work unit. The first objective is to identify new spacecraft systems electronic packaging and cabling requirements and develop concepts which may provide substantial improvements in future spacecraft systems reliability. The second objective is to conduct additional study and research on the characteristics and effects of high-voltage phenomena, i.e., corona and arcing, in the critical pressure region in order to gain technology to support a high-voltage electronic equipment design specification. The third objective is to study, evaluate, and develop advanced interconnection techniques. The fourth objective is to develop nonmagnetic interconnect welding materials and technology, and the fifth objective is to increase electronic circuit interconnect reliability.

SUBSTITUTION OF A PRINTED CONDUCTOR ASSEMBLY FOR THE MARINER C UPPER RING HARNESS

A considerable weight saving can be achieved by substituting a printed conductor assembly (PCA) for a conventional wire cable harness, but the electrical performance of a PCA in a complex spacecraft system is difficult to predict. To evaluate this approach, a two sided printed conductor assembly was designed and fabricated as a direct substitution for the upper ring harness and trough assembly in Mariner C. This ring harness provides 725 electrical connections at the interface among the eight bays around the periphery of the spacecraft. The voltages range from millivolts to 50 v; frequencies of dc, 400 cps and 38.4 kc sine wave, and 2400 cps square wave. Pulse durations from microseconds to 300 millisec occur in some circuits. Since shielding is not easily accomplished in a printed conductor assembly, sensitive circuits were removed as far as possible from the 2400-cps square wave power conductors. A minimal use of ground planes for electrostatic shielding was made, and the ac power circuits were transposed from side to side to reduce electromagnetic and electrostatic coupling with low level signal circuits. In the original cable harness, this was accomplished by twisted wire.

To allow minimum modification of the Mariner C PTM for the test, jumper cables were required between the PCA and the electronic assembly cables. Figure 1 shows the PCA mounted temporarily on top of the cable trough of the PTM with the various jumper cables in place, Rows of terminals just inboard of the PCA connectors were provided to allow rerouting of various circuits by interrupting the printed conductor and substituting an insulated wire, shielded if required, for circuits found to be adversely affected by noise pickup during the PTM test.

The electrical test consisted of photographing the noise level of over 100 typical circuits during operation of the spacecraft using an oscilloscope camera with the standard breakout boxes connected between the conventional ring harness and the bay harnesses. The PCA was then installed on top of the harness trough, and connected to the electronic assembly harnesses with the jumper cables. With the scope settings the same as before, each measurement was repeated and compared with the corresponding measurement taken previously.

The results were that in 95% of the circuits measured, the noise level was equal to or less than that in the conventional wire ring harness. In the remaining 5% the noise level was slightly higher, but still well within specification; consequently, from an electrical performance standpoint, the printed conductor assembly is a flight-quality item. Upon completion of a mathematical analysis of the effectiveness of twisting and transposition on noise reduction, a final report will be prepared.

HIGH-VOLTAGE ELECTRONIC EQUIPMENT PROTECTION

Corona and voltage breakdown phenomena occurring in electronic equipment utilizing high voltages and operating in the critical region are being investigated from several different angles. A very sensitive corona detection network is being developed which allows corona currents of a fraction of a microampere to be measured. The detectable corona level is far below that which is visually observable and use of a photomultiplier tube is required for optical detection. A photomultiplier circuit has been built up, but has not yet been tested due to other tests in progress.

Point-to-plane corona and voltage breakdown tests have been completed showing that the minimum separation required for the transition from arcing to corona increases as the pressure is decreased. The voltage breakdown also decreases with pressure to a minimum and then increases. Measurements at pressures lower than the minimum voltage breakdown region need to be repeated after the test setup is rebuilt to eliminate all metal above the plane, Figure 2 shows the present point to plane setup in the vacuum system.

A workshop on "Voltage Breakdown in Electronic Equipment at Low Air Pressures" was held at JPL in August. A total of 125 persons attended and 33 papers were presented. Proceedings of this workshop are now in preparation as a JPL TR. One of the points of controversy considered at the workshop was the effectiveness of foams as high voltage insulation in a hard vacuum. Hughes and some other organizations ran tests and concluded that polyurethane foams were very good while JPL experience has been the opposite.

In an attempt to reconcile this controversy, several tests on foam samples have been run at JPL. Four foam samples as shown in Fig. 3 have been fabricated from material supplied by Hughes. The electrode configuration is the same in all samples as visible in numbers 3 (lucite window) and 4 (open). Sample 1 consists of this electrode configuration embedded in a block of solid foam while 2 has a triangular cavity, similar to 3 and 4. These samples are at present being exposed to a hard vacuum of 10^{-5} mm. The ac corona onset voltage below 11 kv, if it exists, is measured. By comparison with a voltage-breakdown-vs-pressure curve run on sample 4, the average pressure between the electrode in each of the other three samples can be measured from the corona onset voltage.

Technical assistance was given and equipment loaned to Section *382* for voltage breakdown tests of polyurethane foams. A voltage high enough to produce a continuous corona in a hard vacuum was applied and eventually caused arcover within the sample.

A rough draft of a high-voltage specification for Voyager has been prepared but is held in abeyance due to higher priority work.

ADVANCED INTERCONNECTION TECHNIQUES

Parallel Gap Welding

The recent packaging design for the OGO-E Plasma Probe includes integrated circuit flat packs installed in a molded plastic stick module. As shown in Fig. 4, the flat pack ribbon leads (gold plated Kovar) are attached to weldable terminal of 0.020 in. thickness.

A parallel gap welding technique is employed in which both electrodes bear against the uppermost weldment material and the flow of welding current divides between the two weldment materials. The metallurgical bond occurs at the interface of the ***two*** materials in the region of the interelectrode gap.

The terminal material is a gold plated cupro-nickel (Monel 501) and was chosen for this application in consideration of the following factors:

1. Nonmagnetic requirement.
2. Alloying characteristics with gold.
3. Machinability,
4. Specific resistance.

The welding power supply being used for this process is a constant voltage device which senses the dynamic resistance across the electrodes during the weld cycle. The duration of the square wave pulse is adjustable, as is the voltage.

Electrode force being the least critical parameter, it was maintained at a level which stabilized the contact resistances. It was required to minimize the transfer of welding heat through the terminal to the underlying adhesive joint. Accordingly, a pulse duration was established which contributed to sufficient welding energy, and yet satisfied the foregoing requirement.

It was discovered at the outset that the controlling parameter for heat balance is electrode gap, By varying through the range from 0.015 to 0. 030 in., the heat-affected zone can be moved from the Kovar lead into the Monel terminal. An interelectrode gap range of 0.020 to 0.025 in. produces welds in which there is pronounced gold-Monel diffusion, in addition to some recrystallization in both base metals. (See Fig. 5.)

Magnet Wire Welding

A development contract was recently concluded with The Sippican Corporation, Marion, Massachusetts. The statement of work called for an investigation as to the weldability of insulated magnet wire to a suitable terminal pin. The method Sippican used to penetrate the insulation consisted of heating the upper electrode and causing the insulation to soften and split under pressure. Copper magnet wire is highly desired by JPL because of its high electrical conductivity, ease of handling, availability, and nonmagnetic property. Sippican's opinion, based on their work, is that copper is undesirable for welding because of its high conductivity and decrease in tensile strength at the weld zone. Their final recommendation is to weld Formvar coated nickel wire to Alloy 142 (Ni-Fe) pins.

JPL has been making an effort to prove the feasibility of welding copper magnet wire to a stainless steel terminal, using Sippican's hot electrode technique. Results as of this date indicate that Formvar coated copper wire can be welded to the stainless steel pins over a fairly wide range of machine settings. Weld strengths of 70% of the ultimate tensile strength of the wire are consistently obtainable. Polyurethane insulation is unsatisfactory because of its tendency to flow and contaminate the electrodes. Future work will be done with a larger range of wire sizes and other terminal materials,

NONMAGNETIC INTERCONNECT WELDING MATERIALS

This subtask is directed to develop a nonmagnetic interconnect welding material to replace nickel ribbon for use in applications such as the intraconnection of component leads within welded cordwood modules.

Nonmagnetic materials to replace nickel are being investigated to the following three considerations:

1. Interconnection reliability
2. Weldability with conventional resistance welding equipment
3. Ability to directly replace nickel ribbon within a welded cordwood module.

Many different elements and alloys have been evaluated to date including palladium and various cupro-nickel alloys. Alloy 90 (11% nickel, balance copper) is presently being evaluated extensively, and the results to date look promising, although some additional alloys such as silver-palladium will be further investigated.

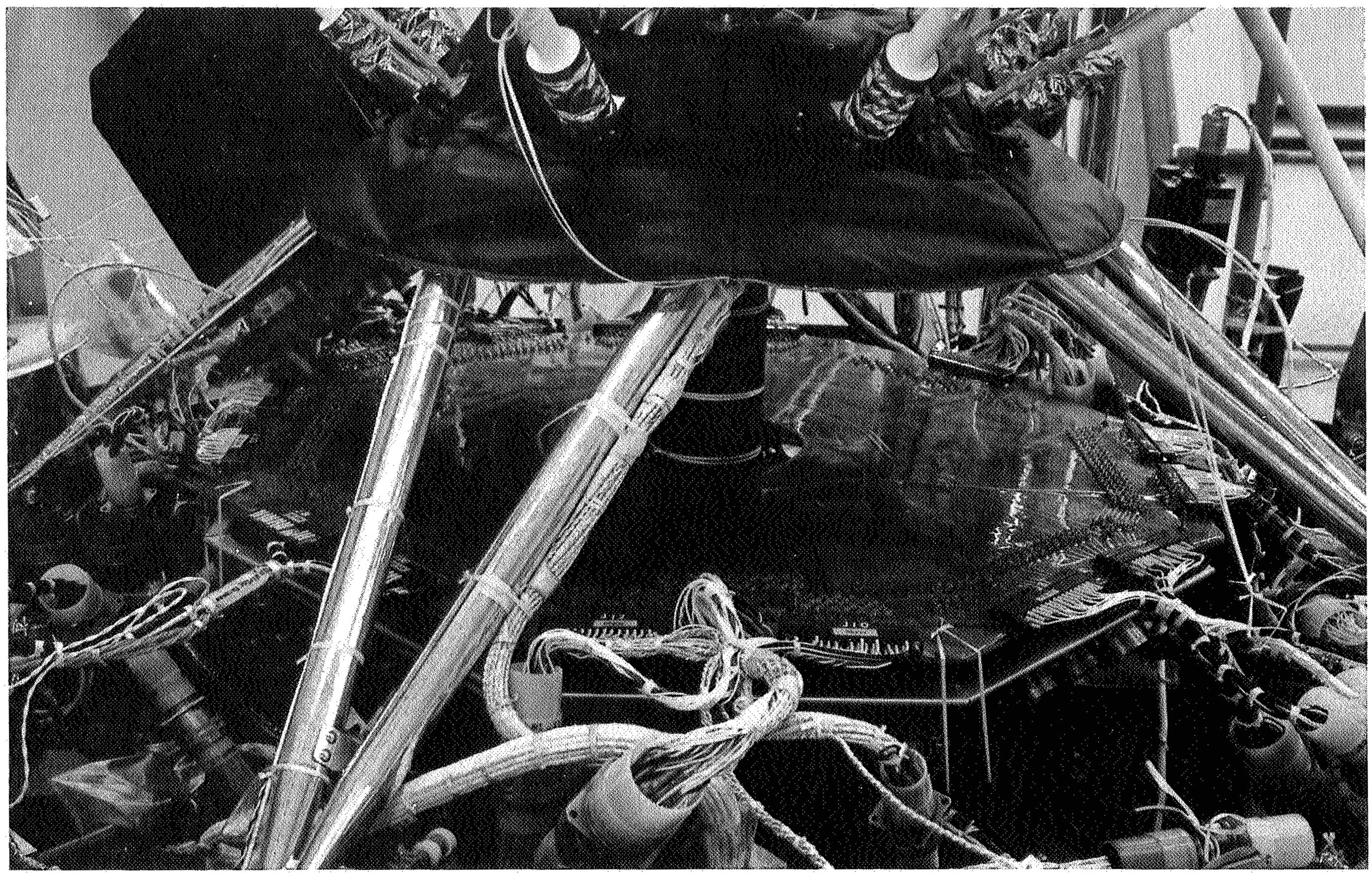


Fig. 1. Printed conductor assembly under test on PTM

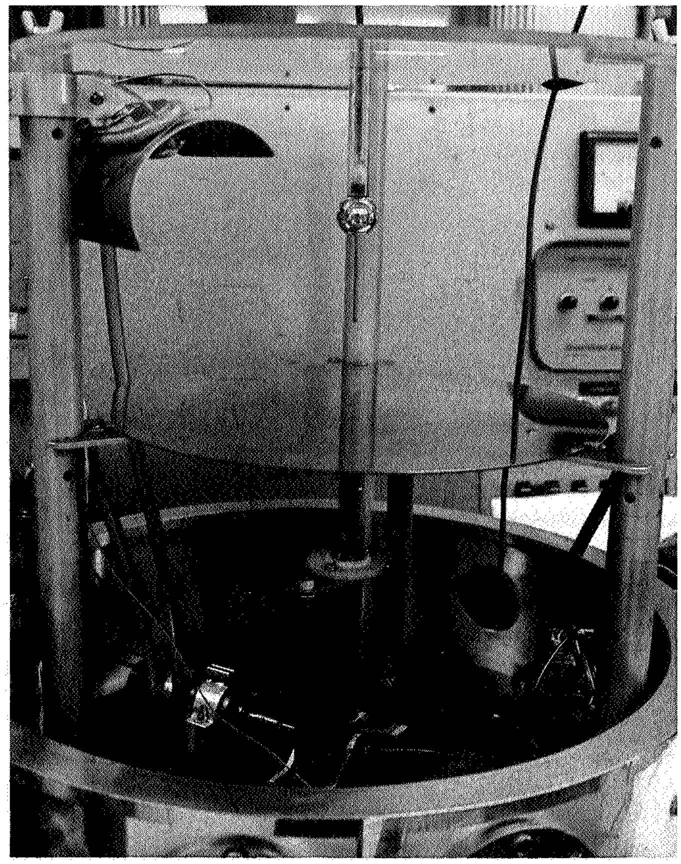


Fig. 2. Point-to-plane voltage breakdown test setup vacuum system

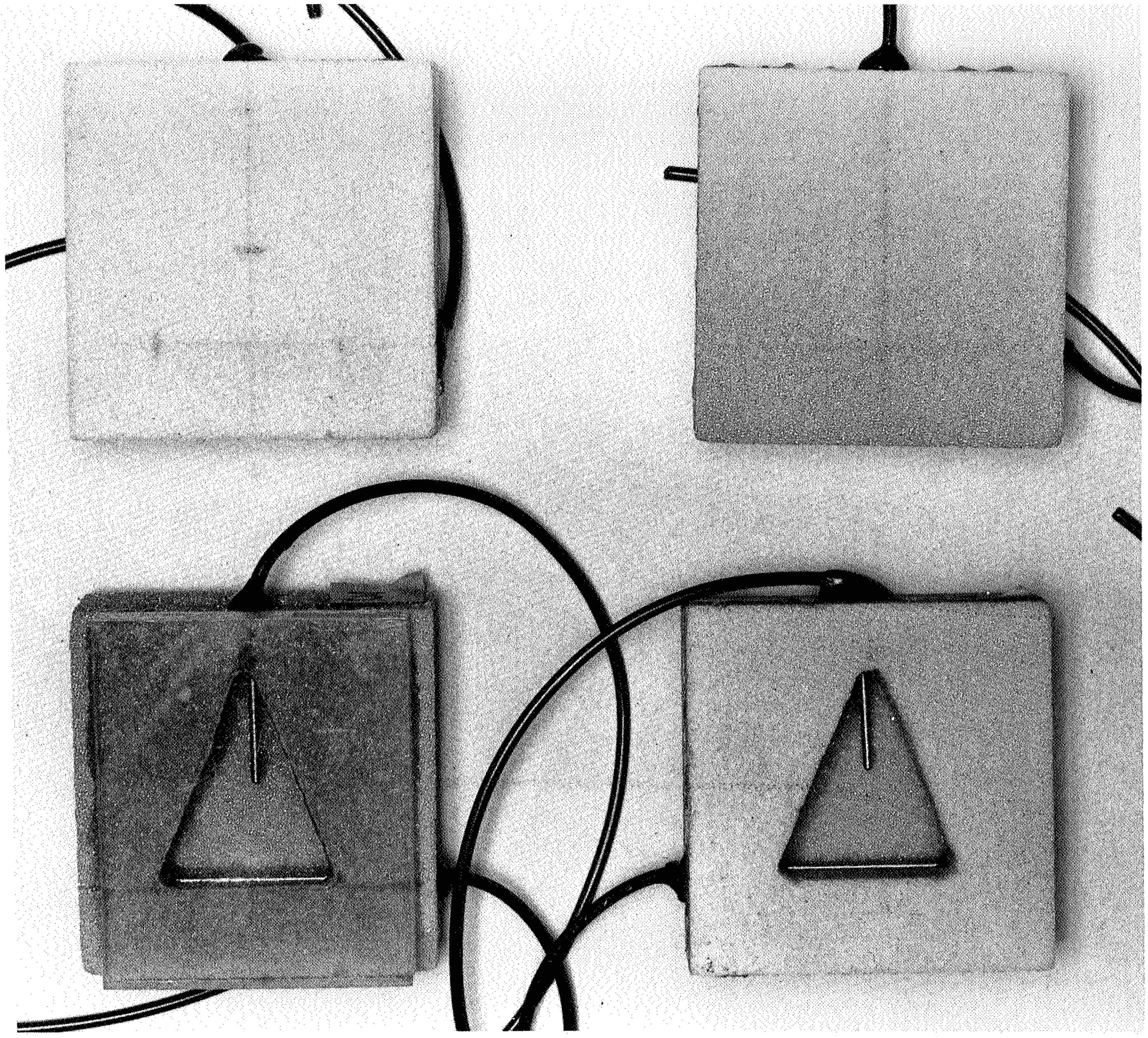


Fig. 3. Polyurethane foam test samples for measurement of gaseous diffusion rates

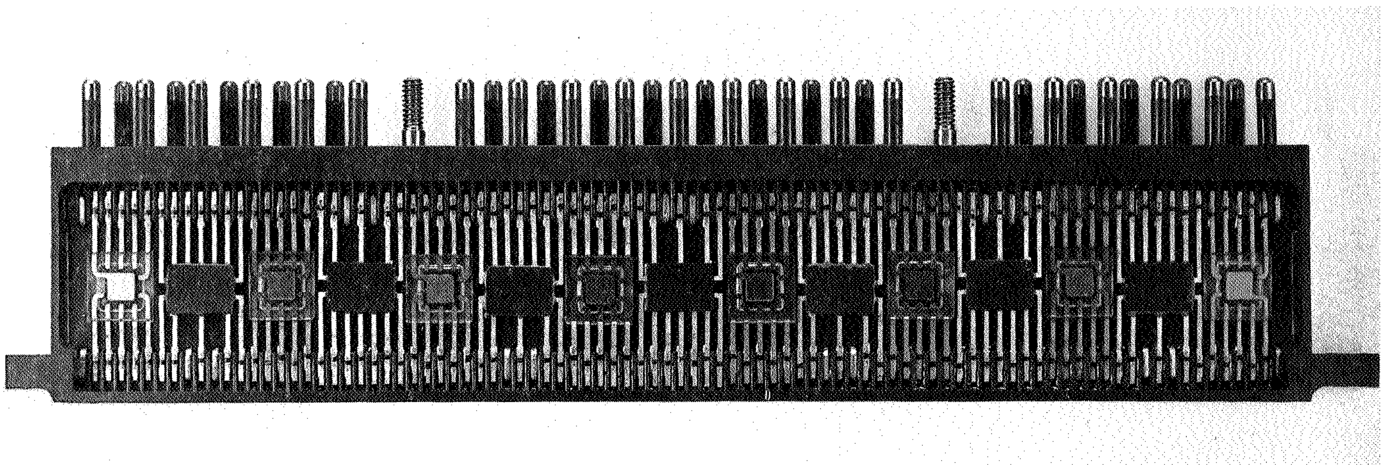


Fig. 4. Stick module with flat packs in place

Fig. 5. Gold-plated Kovar lead welded to gold-plated Monel terminal (200x)

MICROELECTRONIC PACKAGING ADVANCED DEVELOPMENT
NASA Work Unit 125-25-03-02-55
JPL 325-50201-2-3570
L. Katzin

OBJECTIVE

The long-range objectives of this unit are four fold. First, there is the task of maintaining cognizance of the present and projected state of the art. This task includes the study and evaluation of new developments in integrated circuit packaging configurations for future spacecraft applications. Second, is the task of recognizing voids in the technology required for spacecraft microelectronic packaging, and then developing designs and techniques to fill them. The third objective is the application of the information collected and developed to advantageous usage on flight spacecraft projects. The fourth objective is to study and evaluate existing microbonding interconnection techniques, and to develop more reliable techniques if required.

ADVANCED DEVELOPMENT

Integrated circuits in flat-pack geometry have been packaged in two forms, the stick modules and the 3-D module. The stick module shown in Figs. 1 and 2 are capable of accepting and fully interconnecting as many as 15 ten-lead integrated circuits or a combination of various flat packs and discrete components. Because of the length-to-width ratio of the stick, 39 input and output terminals on 0.100 in. centers are made available on one edge of the stick module. The gold plated terminals within the stick are made of nonmagnetic Monel 501, which offers both solderable and weldable properties. The stick modules have been dynamically tested in a chassis frame with an input of 5G RMS in 3 axes. There was a gain of 10 along the horizontal axis and 20 on the vertical axis (which is 95G). The unit successfully passed this excitation. A paper was presented on the early phase of this development at the National Electronic and Production Conference held in Long Beach, California in June, 1965. The major advantages of this method of packaging are flexibility of component usage, the ease of modification and repair, the short lead time requirement, and the accessibility for inspecting and testing,

A 3-D method of packaging flat pack devices was required to complement conventional component cordwood packaging systems. Work on this form of packaging is in the early development stages, The same advantages stated for the stick geometry are the objectives of the 3-D module. To date, three designs are being considered, and prototypes will be evaluated for each approach.

The most essential part of a packaging concept is the method of interconnecting For both the stick module and the 3-D module a magnet wire interconnection scheme was used. Magnet wire, which is the same material used to string memory cores and wind coils, has the advantage of thin but reliable insulation which can be selectively removed. Because of this capability, either point-to-point or routed wires can interconnect a series of terminations without cutting the wire at each attachment point. Also because of the thin coating of insulation, many insulated crossovers can be accomplished without building up a deep mesh, With this technique, the complexities of multilayer printed circuit boards are satisfied without the associated production and reliability problems. Figure 3 shows 400 points on 0.050-in. centers, interconnected by a single piece of magnet wire.

The magnet wire connections can be either soldered or welded. On the present stick module, the magnet wire is soldered to the terminals. In Fig. 3 the wire has been welded to the terminals. The components (flat pack or conventional) may also be soldered or welded. On the stick module, the flat packs are parallel gap welded and the discrete components are soldered.

Integrated circuits in TO-5 cans are packaged in the same manner as discrete transistors, in either cordwood or planar modules. Carriers for handling and testing flat-pack devices are being evaluated. Special carriers are being designed to accommodate a single flat-pack device for use in a cordwood package where the ribbon leads of the device are attached to the round leads of the carrier. This makes the flat pack compatible with other components for cordwood packaging.

A new stick module is being developed which will have the advantage of molded in planar terminals. It will also have the option of molding in all of the interconnecting wires of the stick and will allow geometry flexibility with a minimum of time and tooling.

Development work is continuing in both soldering and welding. Reflow soldering with pulse heating is being evaluated as are techniques for multiple, simultaneous solder joining of flat-pack leads to their respective terminals. Welding of magnet wire through the insulation is being developed with oxygen-free high-conductivity copper, gold-plated and insulated with heavy formvar. The results to date are very encouraging.

APPLICATIONS

The stick module, as developed and tooled, is presently being used on the OGO-E Plasma Probe (approximately 300 flat packs per system) and also on the biosatellite. The critical data recorder for the Surveyor has been committed to the flat packs. The experience being acquired by the above projects in the usage of this technique is encouraging other flight projects to consider the stick module. The 1969 Mariner spacecraft will probably use the new stick module that is presently being developed. The Voyager program is also considering use of the new stick module.

PROJECTED EFFORTS

Development work planned for the next period will include continuation of the stick and the 3-D module development, and the completion of the soldering and welding development efforts. New efforts will include studies of multiple chip and flip chip application for high-density packaging, and the microbonding techniques associated with these processes.

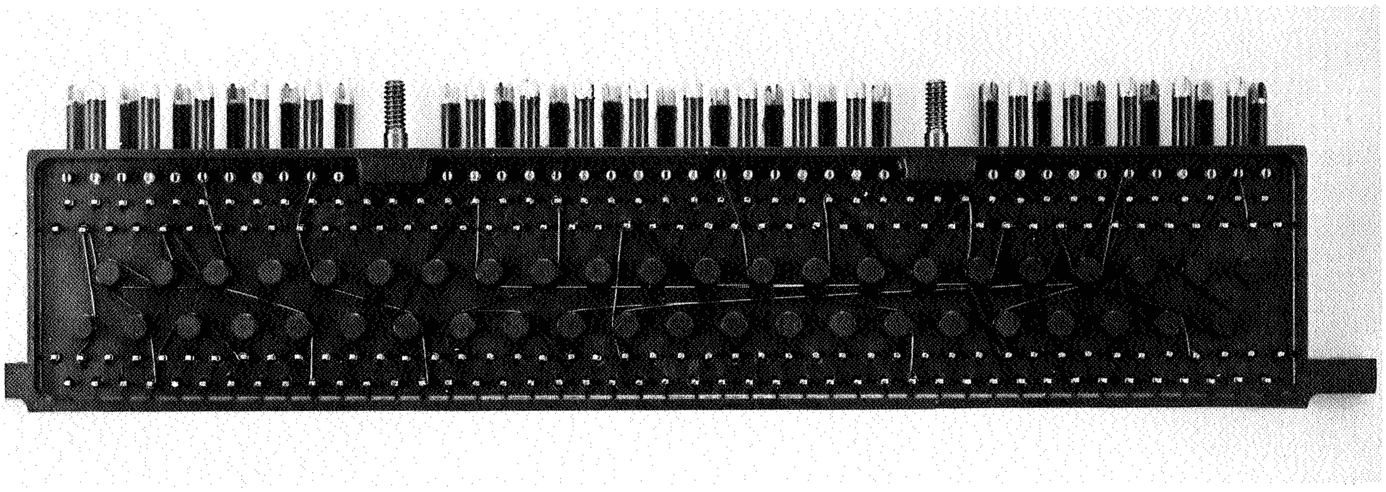


Fig. 1. Stick module wiring

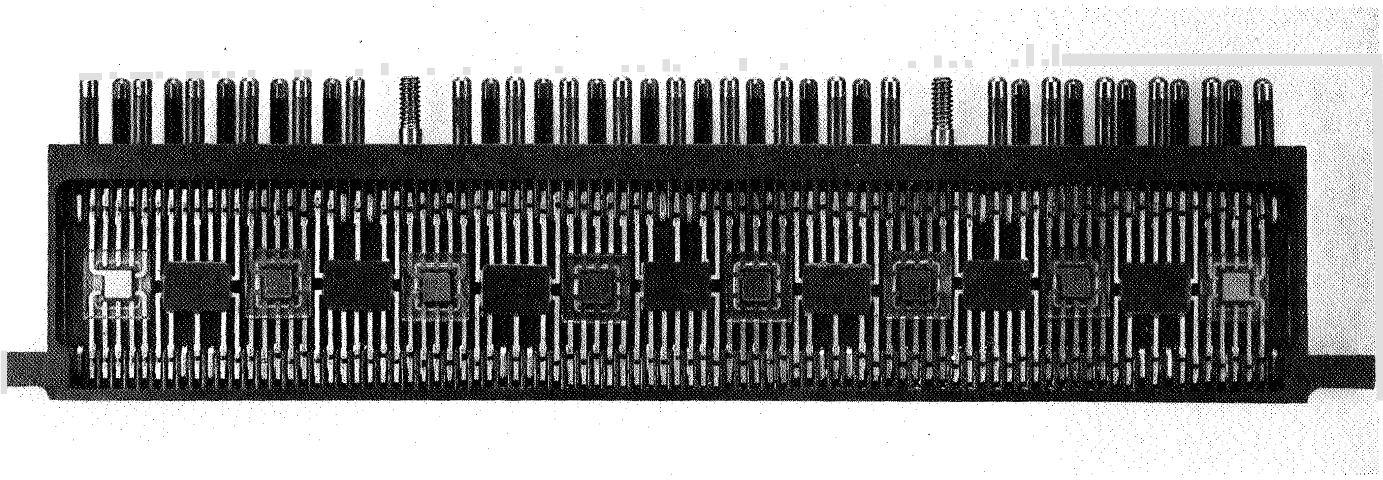


Fig. 2. Stick module with flat packs in place

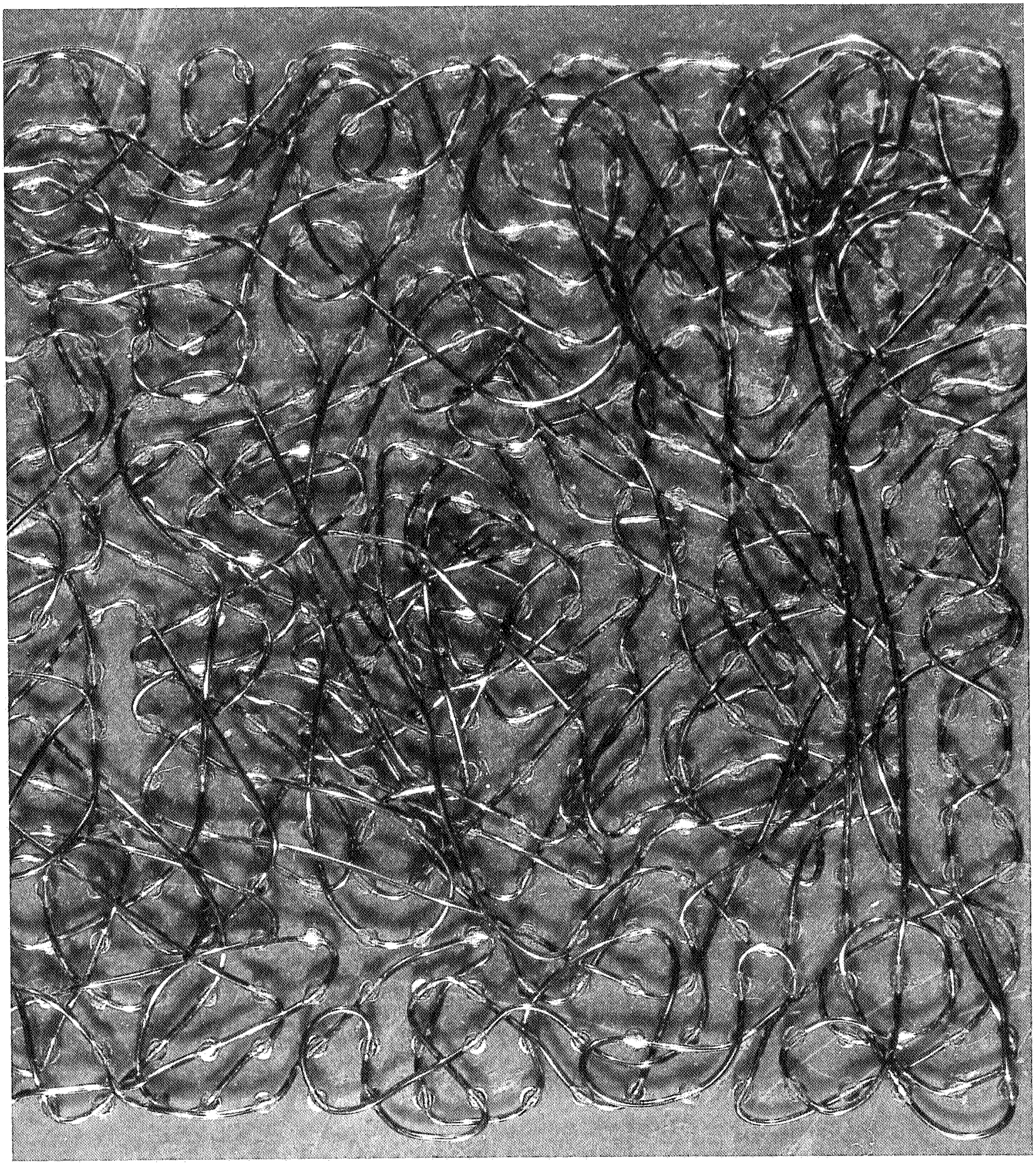


Fig. 3. Welded magnet wire

MICROELECTRONICS DEVELOPMENT AND APPLICATION

NASA Work Unit 125-25-04-01-55
JPL 325-50301-2-3340

D. Bergens
J. Duffy
J. Ponder

OBJECTIVE

To apply integrated circuit technology (both monolithic and thin film) to the synthesis of advanced planetary spacecraft telemetry, command, and data storage systems. The primary goal is to exploit size, weight, and power savings to achieve an increase in reliability. This is a continuing development and application effort in preparation for more specific project oriented activities as the state of the art permits.

APPROACH

Commercially available digital and linear integrated circuit devices have been purchased for in-house testing. Development of custom integrated circuit devices or functional subsystems such as analog multiplexer switches, command isolation switches, analog-to-digital converters, ranging code generators, an 8-channel commutator deck, and 20- and 30-bit memory devices have been undertaken. The requirements of high impact shock, radiation resistance, and sterilizability have been imposed in anticipation of future applications. Work performed during the reporting period is discussed below.

PHOTON-COUPLED MULTIPLEX SWITCH DEVELOPMENT

The life test mentioned in the previous semiannual review was terminated after 6300 hr. Eight out of twenty-five of the switches were still within spec at that time. JPL TR 32-794, Photon-Coupled Multiplex Switch Development, has been published.

Further work on the multiplex switches will consist of proton radiation tests scheduled for January 1966. No contractual work is planned. Another application of photon switch actuation is discussed below.

PHOTON-ACTUATED COMMAND ISOLATION SWITCH DEVELOPMENT

A 13-month cost type contract has been given Texas Instruments, Inc. for the development of a photon-actuated isolation switch. The switch, which provides electrical isolation at the outputs of a spacecraft command subsystem, will be designed for high reliability and packaged in integrated circuit flat pack form per JPL Design Specification XOY-50469-DSN. This procurement was jointly sponsored by NASA Work Unit 818-01-04-02-01 Voyager and 125-25-04-01-55. Texas Instruments, Inc. will start work January 3, 1966. The procurement was discussed at length in the previous semiannual report (JPL TM 33-243).

MICROELECTRONIC ANALOG-TO-DIGITAL CONVERTER DEVELOPMENT

The hybrid (monolithic circuit/thin film substrate) 8-bit, analog-to-digital converter (ADC) was received from Autonetics, Division of North American Aviation on December 8, 1965, over five months late. The delay was caused by faults or failures which resulted in the converter being rebuilt twice. Additional funding was not required since it was a fixed price contract.

The ADC, which is described in detail in the JPL TM 33-243, is faster (300-kc quantizing rate) and more accurate (0.5%) than specified and operates satisfactorily in all respects. The packaging requirement was changed on the final rebuild from an encapsulated module to the configuration shown in Fig. 1. The thin-film substrates with the monolithic integrated circuits are in the three flat packages. The ADC in this configuration weighs 2 oz and has a volume of 2.2 in.^{3}.

Testing of the ADC will continue in the next quarter.

INTEGRATED CIRCUIT SEQUENCER FOR MULTIPLEXING

The planned development of an integrated circuit sequencer for the multiplexing of spacecraft telemetry measurements hinged on the successful completion of a contract Langley has with Texas Instruments, Inc. as discussed in the previous review. This development, requiring the fabrication of NPN and PNP transistors on a monolithic silicon chip, is quite difficult, and perhaps beyond the state of the art from a practical standpoint. The sequencer development has therefore been redirected toward MOS-FET array technology. The new development is discussed below under the heading "Eight Channel Commutator Deck."

No contract was let and no further activity is planned on the sequencer.

DIGITAL INTEGRATED CIRCUIT INVESTIGATIONS

An investigation of low power digital integrated circuits has been started as an in-house task. The field was surveyed. Small quantities of the more promising circuits have been tested, and certain tentative conclusions drawn, Circuits tested included two Fairchild lines, milliwatt micrologic and the new 9040 series, the Philco MEL line, Signetics 400 series, and Texas Instruments, Inc. series 51. A JPL internal document on the preliminary phase of the investigation of low power digital integrated circuits has been prepared.

This investigation will be continued, time permitting, with in-depth study of the circuits listed above. New low power circuits will be included in the investigation when appropriate.

Another on-lab activity is participation in the Digital Integrated Circuit Working Group. The goals of the working group are: (1) to provide a forum for discussion of on-lab activities in digital integrated circuits, (2) avoidance of duplication of effort in test and evaluation, and (3) the ultimate definition of several digital families which best satisfy spacecraft requirements. The working group consists of engineers from throughout JPL who are concerned with the application or evaluation of digital integrated circuits.

A symposium was attended at Langley Research Center August 10 and 11 on MOS transistor technology. The symposium was presented by RCA.

LINEAR INTEGRATED CIRCUIT EVALUATION

Objective

The objectives of the linear integrated circuit evaluation are:

1. Establish a level of confidence in current linear integrated circuits.
2. Establish a level of confidence in manufacturer's published specifications.
3. Learn linear integrated circuit tradeoff's, advantages and disadvantages over equivalent discrete circuits.

Present Status

A total of twenty-two tests have been performed on each of sixty-one linear integrated circuits. Types of circuits tested have been: (1) differential amplifiers, (2) transconductance amplifiers, (3) thin-film resistor networks, and (4) comparators, The differential amplifiers have also been tested in typical circuit configurations, i. e. , operational amplifiers, potentimetric amplifiers and integrators,

Future Plan

A final report on the test results is presently being prepared. This report will complete the evaluation of linear integrated circuits as separate devices. Future efforts will use these devices in breadboard systems.

EIGHT-CHANNEL COMMUTATOR DECK

When it became apparent that design of a commutator sequencer (refer to 'Integrated Circuit Sequencer for Multiplexing") on a monolithic silicon chip was beyond the state of the art for bipolar technology, attention was turned to MOS technology. MOS shift register arrays are well-suited for commutator sequencers; further, MOS devices are good analog switches. It was thought that the present MOS state of the art would allow an eight-channel commutator consisting of an eight-bit shift register, eight analog switches, and control logic to be placed on a monolithic silicon chip.

In December, a design spec for the commutator deck was completed (Spec GMN-50523-DSN) and proposals were solicited. The proposals are not due until mid-January.

20-BIT AND 30-BIT WORD-CELL MEMORIES

In anticipation of need for on-board data processing in future spacecraft, it was decided to solicit proposals for a 20-bit and a 30-bit memory organized as a word-cell (serial in, serial out) to minimize interconnections. The most promising technology for the word-cell appears to be MOS technology in which packaging densities for memories is becoming very high (e.g., one manufacturer markets a 100-bit shift register on a single monolithic silicon chip while a second manufacturer markets a 90-bit shift register on a chip).

In December, a design spec for the word-cells was completed (Spec GMN-50524-DSN) and proposals were solicited. The proposals are not due until mid-January.

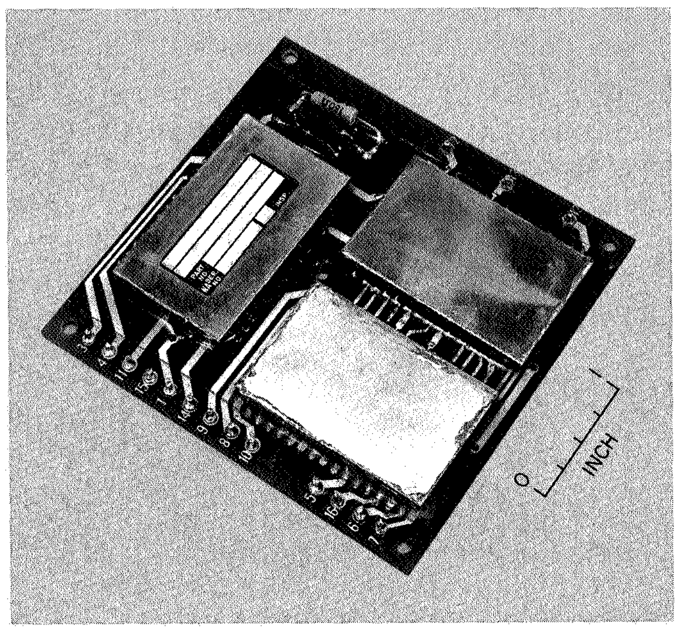


Fig. 1. Microelectronic analog-to-digital converter

MICROELECTRONIC SCIENCE DATA SYSTEM
NASA Work Unit 125-25-04-02-55
JPL 325-50401-x-3240
R. H. Nixon

OBJECTIVE

To develop a microelectronic system design capability for spacecraft flight data handling equipment. Included is the evaluation and qualification of microelectronic components and packaging techniques.

STATUS

Hybrid Packaging Study, NRT Sequencer System

The hybrid integrated circuit sequencer system has completed environmental and bench testing and has been placed on life test where power is continuously applied and the performance of the system periodically monitored.

Integrated Circuit Evaluation

An evaluation of Fairchild Semiconductor's new 9000 series line of low-power digital integrated circuits has been initiated. A small quantity of parts has been ordered for a "quick look" evaluation. A larger procurement of the circuits is contemplated for the purpose of a more thorough evaluation. The more thorough evaluation would include the determination of functional compatibility with existing and proposed systems, qualification for spacecraft use, and the investigation of processes and technology leading to recommendations for reliability improvements, etc.

Evaluation of Signetics DTL integrated circuits has continued. A small quantity of circuits was purchased and subsequently fabricated into a typical system performing a data handling function. The same system exists in discrete component form and is being compared directly with the integrated circuit system. Such things as functional compatibility and circuit margins are being compared.

Visits have also been made to groups working on advanced packaging for integrated circuits. These teams, including 3-C and Univac, Blue Bell, are concentrating efforts toward improving the interconnections between active devices (IC's, etc.) and the peripheral circuits. The goal is twofold; elimination of bonded wire leads (a known source of failure) and conversion to automated production by eliminating bonding as a human element in manufacturing.

Participation in a JPL working group on digital integrated circuits has been maintained. The purpose of the working group is to coordinate JPL digital integrated circuit activities, investigate JPL electrical standards for integrated circuits, and maintain communication between engineers in the various JPL divisions.

HUMAN FACTORS SYSTEM (127)

MAN-SYSTEM INTEGRATION (127-51)

REMOTE OPERATION OF A ROVING-TYPE VEHICLE

NASA Work Unit 127-51-01-01-55
JPL 327-10102-2-3430
JPL 327-10102-2-3190

W. G. Wong
V. F. Anthony

OBJECTIVE

The overall objective of this work unit is to advance the state of the art in the remote control of unmanned spacecraft en route to, in orbit about, or on the surface of, the Moon or a planet. Within this context emphasis will be placed on the man-machine interface and interactions to understand problems such as operator selection and training, performance under conditions of large time delay, etc. This effort is divided into two separate but coordinated efforts, which are discussed here.

OPERATOR REQUIREMENTS FOR REMOTE CONTROL FROM SFOF

The objectives of this study are to develop a method to evaluate present and potential requirements for the operator in the command/control loop during SFOF operations, and to derive a conceptual configuration of equipments and operations for an illustrative remote control station (RCS) that satisfies these operator requirements.

In the past, the command and control requirements of spacecraft (Ranger and Mariner) have been met primarily by extensive preprogramming of the anticipated command internal to the spacecraft. Most commands were either initiated automatically with backup ground initiation, or by premission preparation of commands for anticipated command sequences. Future missions (e.g., Surveyor, Voyager) pose problems of a greater magnitude of difficulty because of:

1. Increased requirement for commands in real or near real time.
2. Increase by an order of magnitude in the quantity of command instruction.
3. Now meaningful time delay (two-way transmission time and operator response time) caused by real time control requirements.
4. Desire for direct command capability from the SFOF.

An outside study effort has been started to investigate these problems and arrive at methods and concepts that permit effective planning for future missions. Procurement activity for this study was continued from the previous report period. An RFP was issued July 2, 1965 and proposals were received at JPL on July 16, 1965. After a visit to meet contractor personnel, the technical evaluation committee recommended Serendipity Associates of Chatsworth, California, on August 8, 1965. However, procurement delays held up the contract award until October 22, 1965, when the contractor started work under JPL Contract 951313 for a 4100-man-hr effort.

A study plan for contract performance was prepared and submitted as "Program Plan for a Study to Develop Conceptual Design for Remote Control Station," Serendipity Associates Report TR 34-65-23, dated November 1965. The study activities are shown in a simplified block diagram form in Fig. 1.

This plan outlines the approach for deriving a design concept for remote control and monitoring operations. The first phase in the program is the determination of the functional requirements for a remote control station (RCS). Activities 1 through 4 are necessary for that determination. The next phase, activities 5 through 8, involves the analysis of the elements necessary to meet the performance requirements previously specified. The final phase, besides resulting in an optimally configured remote control station concept, will result in a method to permit the identification and evaluation of the role and requirements of the operators in the remote control station.

Current contract performance is being conducted in accordance with this plan. The first phase was started with the review and analysis of existing and potential missions and mission experiments. The major part of the study will be accomplished and completed during the next reporting period. It is anticipated that the following documentation will be available as a result of this program:

1. Annotated Bibliography - February 15, 1966. A critical review of selected literature on display and control equipment and techniques pertinent to this study.

2. Functional Requirements Report - March 15, 1966. A document specifying the performance requirements of the remote control station in functional terms.

3. Final Methods Report - June 3, 1966. A method to permit identification and evaluation of the personnel role and requirements in the remote control station besides the general method used for the overall contractual performance.

4. Final Technical Report - June 3, 1966. Documentation of the results of the overall contractual effort to include the recommended configuration and implementation of a remote control station, system alternates, and interfaces with the Deep Space Network.

REMOTE CONTROL OF UNMANNED LUNAR AND PLANETARY SURFACE ROVING VEHICLES (Effort began on this portion of the work unit late November 1965.)

Current objectives for the remainder of FY 1966 are to begin evaluation of the concepts of roving vehicle motion control (RVMC) developed for the Surveyor lunar roving vehicle (SLRV) studies and to start adaptation of these concepts, or start the development of other approaches where required, to satisfy planetary operational requirements.

Two control test model (CTM) roving vehicles originally developed by General Motors (Fig. 2) and Bendix (Fig. 3) (JPL Contracts 951056 and 950656) for SLRV control studies have been assigned for use in studies to investigate and develop an understanding of practical problems associated with the remote control of vehicle motion. The vehicles will be delivered to JPL by April 1, 1966 and operational test plans are projected from that date.

Applications for the use of two test sites (Fig. 4) have been submitted for approval. Site A, within JPL boundaries, has been approved. This site is a paved area upon which a formal vehicle test course will be laid out. The course will be devious, contain obstructions, and will be used as a controlled test base for operator selection, evaluation, and training. Site B is in the Arroyo Seco, a natural wash adjacent to JPL, and has varied terrain including obstructions, slopes, loose soil, and dropoffs. This site will be used for experimental study and verification of concepts pertinent to the remote control of maneuvers, navigation, pitfall avoidance, and operator judgment and decisions, and for exercise and evaluation of on-board protective devices.

Two Forms, OEP-88 "Application For Frequency Assignment Action," have been submitted. The requests are for authorization of the Citizen's Band vehicle control transmitter and the CTM vehicle-based television transmitter.

Laboratory space has been allocated in the Guidance Laboratory, Building 198 (Fig. 4). The space will be used for vehicle checkout, maintenance, and storage. A remote operational control station will be set up in the laboratory. Site B is visible from the top of the Guidance Laboratory building. The laboratory has ground level, double-door entrance, opening directly onto a small paved area that will be used for preliminary familiarization, checkout, and tests.

Arrangements have been made to use a JPL-owned van for a mobile operational control station. It will be used when operating vehicles beyond the communications range of the low-power remote control equipment from the laboratory in Building 198, or when the communications line of sight is obstructed. This van was used for control and transportation of the CTM vehicles during earlier SLRV studies.

PLANS (PROJECTED INTO FY 1966 AND BEYOND)

Within the scope of the objectives, the RVMC study plans recognize particular mission-dependent areas requiring further study. These include, but are not necessarily limited to:

1. The development of methods to select, train, test, and provide operators who have a feeling of "close attachment" in the man-machine relationship. This will necessitate extensive training so that the operator thinks and lives "remote control."

2. The determination of what constitutes minimal, yet ample, data for complete operational control of vehicles to meet mission requirements. This will include items such as relevant data, redundancy, malfunction analysis by deductive methods, and data access speed.

3. The exploration and experimental verification of minimal-attention data display techniques, including display arrangement and form (pictorial, symbolic, and alphanumeric) as they affect operator efficiency, accuracy, attention, and fatigue. Operational consoles and data displays are the direct link in the man-machine interface.

4. The investigation of the balance between on-board and remote control with particular attention to improving channel-use and vehicle time-use efficiency where limited channel capacity and long communication lag-times exist.

5. The recognition of limitations in the capabilities of the man-machine system as they affect mission specifications.

6. The development of on-board protective devices to protect the vehicle in situations beyond the control capability of the operator.

To be useful and effective, all RVMC designs and recommendations will consider the capabilities and implementation of the SFOF and DSN systems, and the RVMC operations station and operators will be integrated into the team and mission-independent requirements of those systems.

Plans for the second half of the present fiscal year (FY 1966) will, before the receipt of the vehicles, be directed toward:

1. Completion of the test site acquisition and preparation.

2. Finalizing communications authorization.

3. Preparation of the laboratory space.

4. Preparation of the mobile operational control station.

After arrival of the vehicles, there will be 1 month of familiarization and checkout of the vehicle and control equipment, plus installation of the control equipment in the control station(s), followed by exploratory operational tests at Sites A and B.

Also, during the second half of FY 1966, effort will be directed in support of the study contract let by the DSN Systems Section at JPL to Serendipity Associates for the development of a "Conceptual Design for a Ground Control Station." This work is related to and affected by the RVMC studies.

Technical contacts will be established with other agencies (e.g., MSFC) interested in, or doing work related to RVMC.

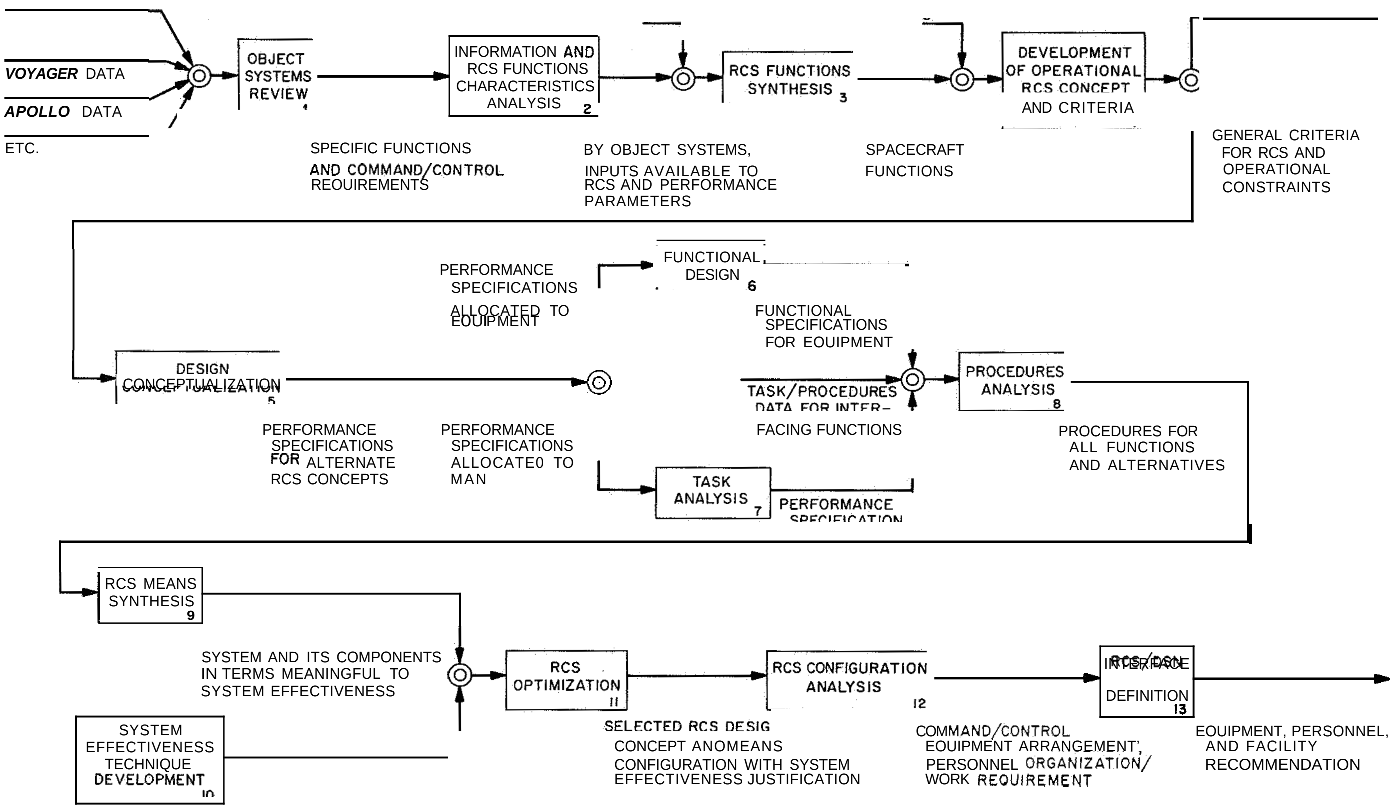


Fig. 1. Simplified program plan flow diagram

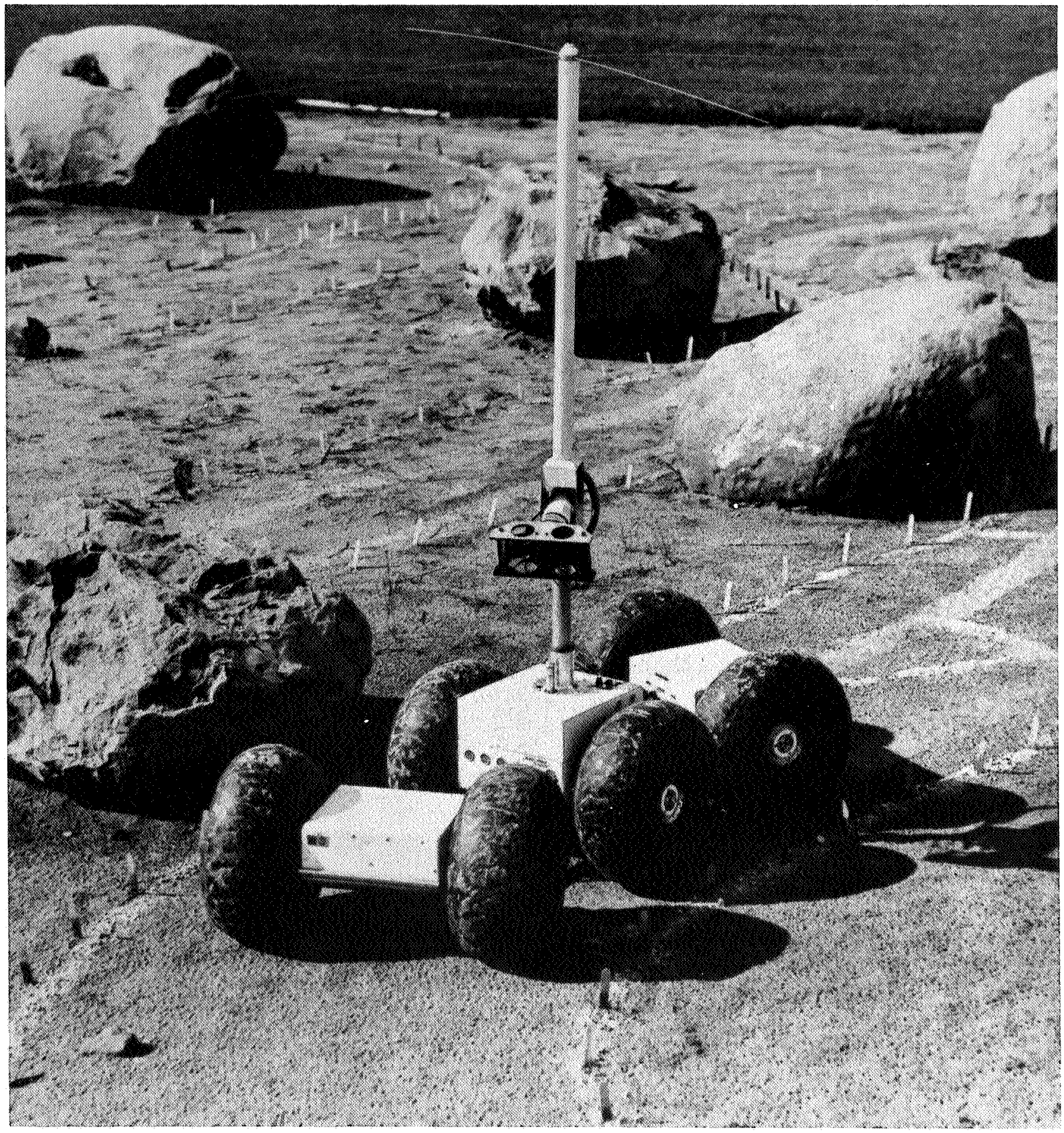


Fig. 2. General Motors engineering test model

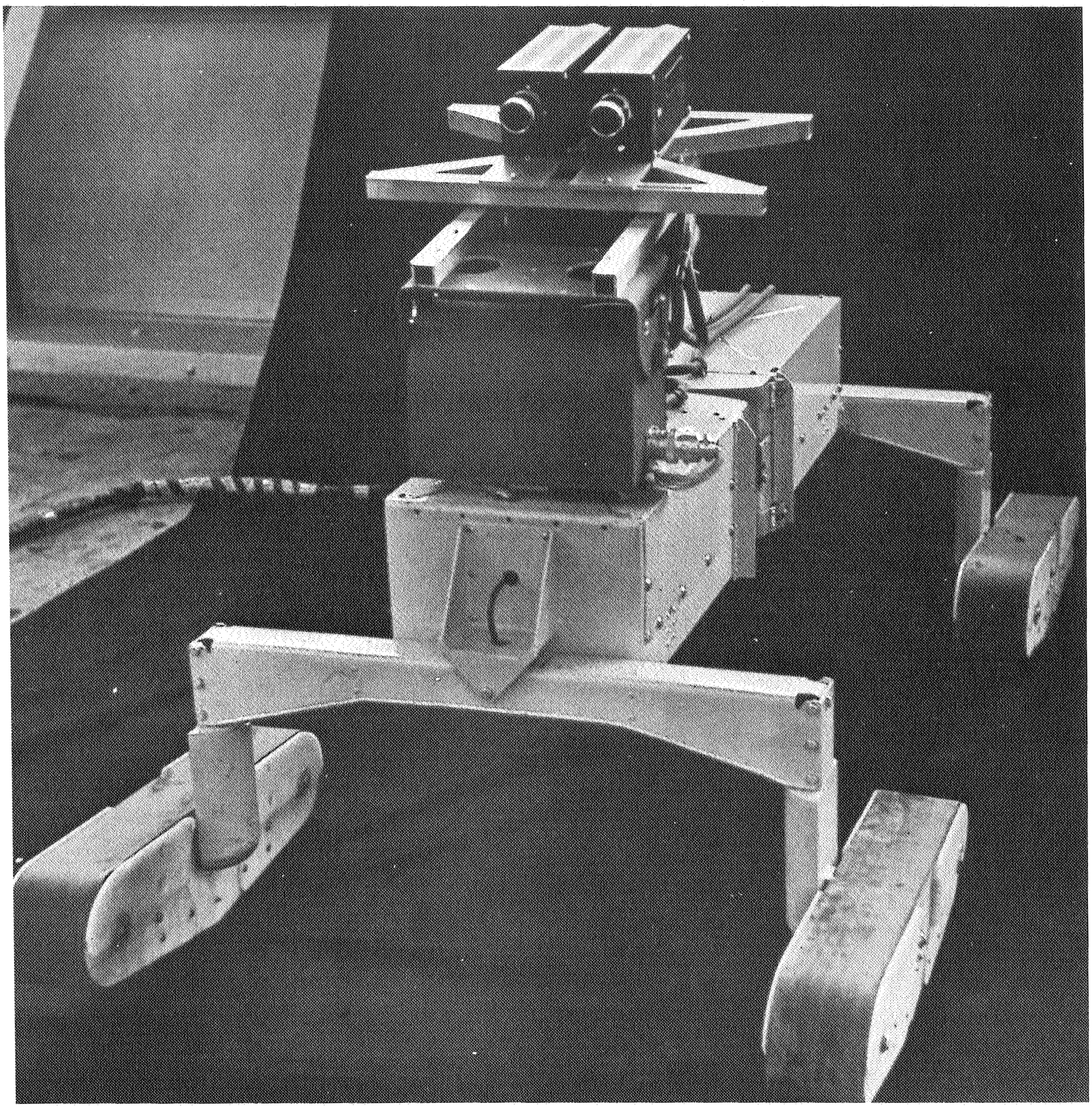


Fig. 3. Bendix SLRV engineering test model

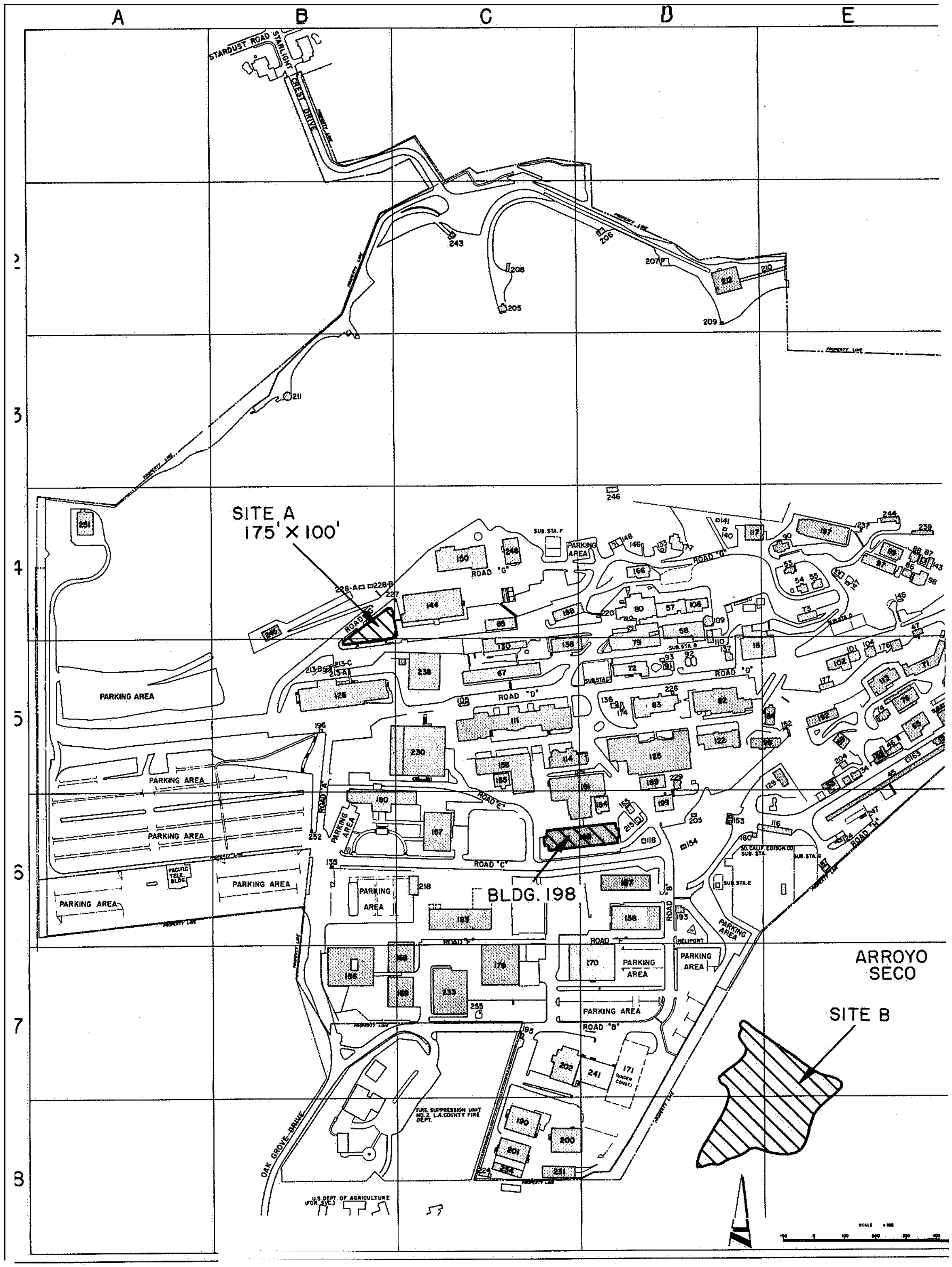


Fig. 4. JPL site plan showing test sites A and B

CHEMICAL PROPULSION (128)

LIQUID PROPULSION TECHNOLOGY (128-31)

ADVANCED TECHNOLOGY CONTRACT MANAGEMENT

NASA Work Unit 128-31-01-04-55
JPL 328-10401-2-3840

C. R. Foster

OBJECTIVES

The objectives of this work unit involve the technical management of advanced development programs for NASA OART.

ACTIVITIES

The purpose of advanced technology contracts, let by the Liquid Propulsion Technology (RPL) office and the Liquid Propulsion Experimental Engines (RPX) office at NASA Headquarters, is to advance the technology of all phases of liquid propulsion through contracts to industrial aerospace firms. Under this work unit, JPL engineers experienced in the liquid propulsion field, provide the technical management of some of these advanced technology contracts. These advanced technology contract management tasks are supplementary to the normal in-house assignments of these engineers on research, advanced development, or flight projects.

In general, the work consists of visits to the contractor's plant for technical information and direction, review of monthly progress reports, and quarterly reviews of progress at the contractor's plant, normally in company with the NASA Headquarters Project Manager. The engineer prepares the statement of work for proposed new (or continuing) advanced technology contracts, provides technical evaluation of proposals received, and gives technical review and approval to the final reports that are submitted by the contractor. On a bimonthly basis, the engineer submits an informal report to the NASA Headquarters Project Manager to give his technical judgment on the status of the contractor's actual effort and results as compared with proposed efforts.

Table 1 lists advanced technology contracts that have been in effect during the first half of FY 1966 and were technically managed by engineers in the Liquid Propulsion Section (384) of JPL. It is expected that technical management of advanced technology contracts will continue at about the same level of effort during the second half of FY 1966.

Table 1. Advanced technology contracts

Contract number	Contract name	Contractor	Contract period	Contract amount	JPL technical manager
NAS 7-102	Study of Static and Dynamic Seals for Liquid Rocket Engines	General Electric Company	October 1964 - Sept. 1965	$ 50, 000	R.S. Weiner
NAS 7-107	Advanced Valve Technology for Spacecraft Engines	Space Technology Laboratories	November 1964 - Sept. 1965	$ 50, 000	L. R. Toth
NAS 7-113	Protective Coatings for Refractory Metals	IIT Research Institute	December 1964 - November 1965	$ 25, 000	R. D. Cannova
NAS 7-149	Study of Zero Gravity Positive Expulsion Techniques	Bell Aerosystems Company	June 1965 - February 1966	$ [illegible]00, 000	R. N. Porter
NAS 7-169	Investigation and Development of Propellant Feed Systems for Manned Space Vehicles	Aerojet-General Corporation	December 1964 - March 1966	$ 75, 000	R. N. Porter
NAS 7-304	Chamber Technology For Space Storable Propellants	Rocketdyne	July 1965 - April 1966	$4[illegible]5, 000	C. R. Foster
NAS 7-305	Experimental Auxiliary Rocket Engines	Bell Aerosystems Company	July 1964 - October 1965	$8[illegible]8, 000	D. D. Evans
NAS 7-372	Study for Development of an Experimental Hydrazine Auxiliary Rocket Engine	Rocket Research Corporation	April 1965 - April 1966	$194, 000	T. W. Price
NAS 7-373	Advanced Pyrolytic Spacecraft Rocket Chamber Materials	The Marquardt Corporation	May 1965 - July 1966	$200, 000	W. H. Tyler
NAS 7-376	A Theoretical Investigation of Liquid B[illegible]	Aerojet-General Corporation	June 1965 - March 1966	$ 63, 000	R. A. Rhein
NAS 7-388	Completion of Design Data for Pressurized Gas Systems	IIT Research Institute	June 1965 - January 1966	$ 75, 000	R. N. Porter
NAS 7-396	Le[illegible]k [illegible]n Manual	General Electric Company	July 1965 - May 1966	$ 40, 000	R. S. Weiner
NAS 7-417	Metallurgical Processing Technology for Hafnium - Tantalum Alloys	Fansteel Metallurgical Corporation	September 1965 - September 1966	$246, 000	R. D. Cannova
NAS 7-436	Research and Development in Art of Valves for Propellants and Pressurants in Space Exploration Vehicles	TRW, Incorporated	October 1965 - October 1966	$150, 000	L. R. Toth

REACTION CONTROL GAS SUPPLY SYSTEM

NASA Work Unit 128-31-02-03-55
JPL 328-11001-2-3840

T. A. Groudle

OBJECTIVE

The goal of this task is to advance the technology in those areas of reaction control gas supplies that will support advanced spacecraft designs of the Voyager class.

The objective this fiscal year was to construct, from available hardware, a monopropellant-hydrazine plenum supply system capable of operating through an arbitrary gas demand profile to prove the feasibility of the design concept. This work is being carried out in conjunction with the Spacecraft Control Section (344) under NASA Work Unit 731-13-01-03-55. Also, a study contract was to be let to investigate a vaporizing liquid system technique.

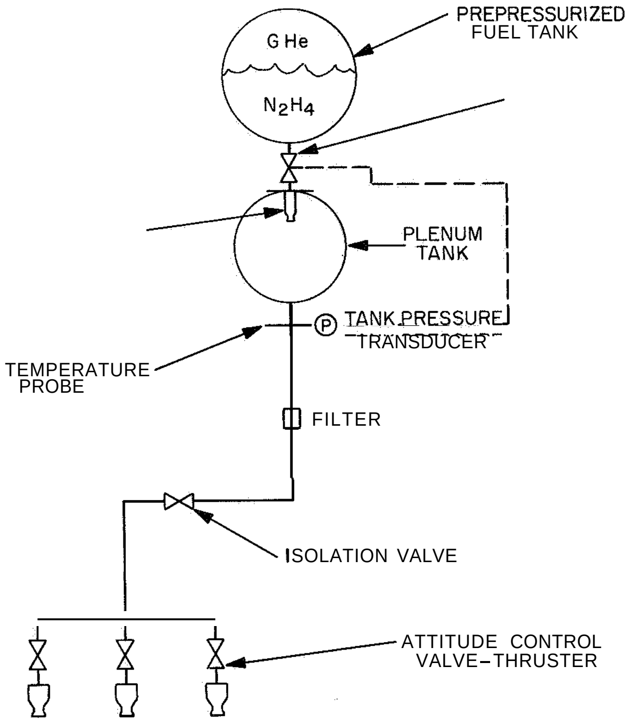
PLENUM SUPPLY SYSTEM

The need for attitude stabilized spacecraft in future mission applications provides a challenge to use improved techniques in the design of attitude control systems. One such system is the hot gas attitude control system using a plenum tank design as shown in Fig. 1. The advantages of low total system mass, possible reliability advantage of substituting a pressure-switch-valve for a regulator, and a simple mechanical design make this device attractive compared with a similarly contrained cold gas system. Because the propellant (anhydrous hydrazine) is stored as a liquid rather than a high pressure gas, the mass of a system based on this design could be about half that of a comparable cold gas system.

In the first half of FY 1966, a series offeasibility demonstration tests were conducted. For these tests, a gas generator of 0.5 lb_f thrust equivalent flow- rate was installed in a plenum tank of 15-in. -diameter (Fig. 1). A modified pressure transducer was used as a pressure switch to operate the generator propellant valve to maintain the pressure in the plenum tank within a preselected bandwidth (± 1.5 psi). The outlet of the plenum tank was attached to a tandem set of filters. These, in turn, were connected to a Ranger attitude control half-system. Figure 2 shows the test apparatus. The standard test-cell hydrazine supply source was used instead of a single tank source shown in Fig. 1. This work has been reported in JPL SPS 37-37, Vol. IV.

Preliminary results of these system tests show that the problem areas such as filtering, pulse mode operation, and heat transfer can be solved by careful component selection and design. Because the use of a moderate size plenum chamber results in relatively high thruster response times and low gas generator pulse rates, the plenum chamber, propellant tank, and gas generating hardware sizes lend themselves to a compact design.

The maximum pulse operations have been necessarily limited by the type of testing performed. However, during the third quarter, a compressed mission profile test (using a self-contained propellant tank) will be attempted for a continuous 32-day period, In the third quarter, a contract will be let to industry for a study program concerning the vaporizing liquid system.



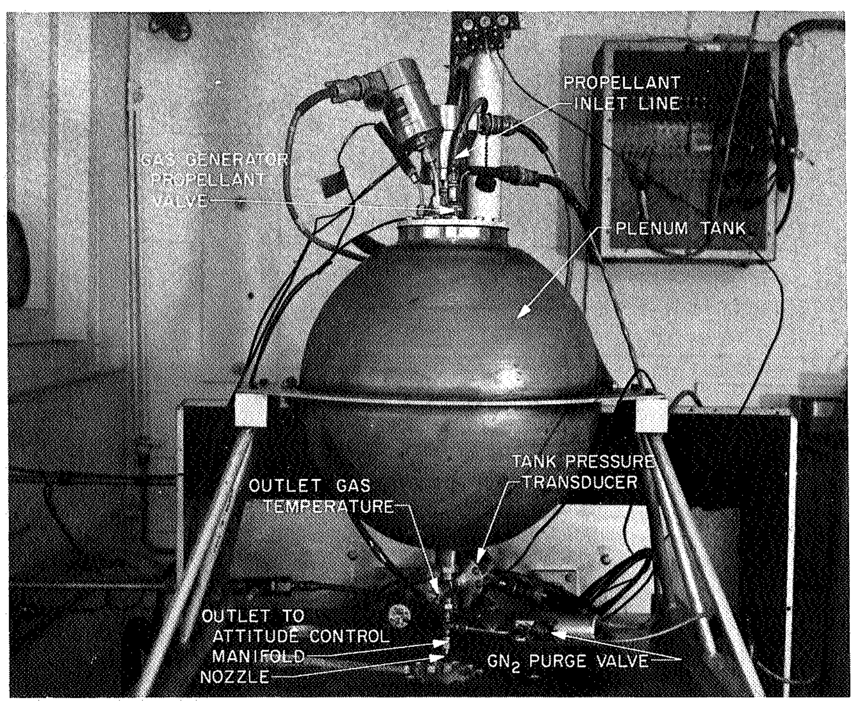


Fig. 2. Hot gas generating system

ADVANCEDSPACECRAFT PROPELLANTS

NASA Work Unit 128-31-05-01-55
JPL 328-10501-1-3840

T. W. Price

OBJECTIVES

The general objective of this work unit is the supply of informational experimental data required for liquid propellant propulsion or power generation systems for lunar and planetary exploration projects at JPL. Specifically, this includes the development of injectors that can be scaled to various thrust levels and are amenable to throttled operation, performance and heat transfer determinations, and thrust chamber and nozzle cooling investigations.

ACTIVITIES

One of the more promising propellant combinations for future spacecraft applications is the oxygen-difluoride (OF_2) and diborane (B_2H_6) system. This combination offers potential payload increases of 25 – 30% over "Earth-storable" propellants. Also, OF_2 and B_2H_6 can be stored as liquids in a space environment by passive control of the propellant tank outer surfaces, and the two propellants have overlapping liquid ranges. The main disadvantages of the propellant system are the toxicity and consequent safety problems of both the OF_2 and the B_2H_6, the corrosiveness and associated handling problems of the OF_2, and the high combustion temperature. The initial objectives are to develop propellant handling techniques, to develop injectors readily scalable to various thrust levels and amenable to throttled operation, to determine performance and heat transfer, and to investigate thrust chamber and nozzle cooling problems.

Progress in modifying the test cell during this report period was steady, although slower than originally planned. Both propellant systems, including the associated cooling equipment, have been installed except for the propellant tank flanges. The flanges have been completed except for installation of the liquid-level gaging systems. A delay of about 7 wk occurred in the mating of the tank flanges and the liquid-level measuring devices. There was an interference between the propellant standpipe and the liquid level stillwell. This required some redesign and rework of the tank flanges.

A chemical scrubber is needed to remove hydrogen fluoride (HF) from the rocket exhaust gases because it is toxic. The HF removal will be made by dissolving it in an excess of water and simultaneously neutralizing the mixture with liquid ammonia. The neutral mixture is then collected and disposed of through the test cell dilution chambers. The scrubber installation is now complete except for the water and ammonia piping and valves, which are scheduled to be installed by the end of January. The cost of the scrubber including design, fabrication, and installation, will be less than $15,000, because an existing diffuser section was modified for this.

The circuitry for a new control panel has been designed and fabricated. This control panel will consolidate in a single location, readily accessible to the test operator, the following items: a digital readout device, leak detection indicators, warning-light controls, propellant tank liquid-level indicators, and valve control switches. This has not been done in the past.

The technician time available for this project has continued to be less than originally planned. Therefore, the overall progress has been slower than planned.

Modification of the test cell is scheduled for completion by the end of April 1966. Major items to be completed are: (1) installation and checkout of the liquid-level gaging systems, (2) installation of the electrical lines between the control panel and the required valves, (3) complete checkout of all systems, (4) passivation of the OF_2 system, and (5) fabrication of injectors and chambers. The first test is now scheduled for June 1966.

RESONANT COMBUSTION

NASA Work Unit 128-31-06-01-55
JPL 328-10601-1-3840

Richard M. Clayton
J. George Sotter
Jack H. Rupe

OBJECTIVE

The objective of this work unit is to find the applicability of a "rotating detonation-like wave concept" to explain the steep-fronted, high-amplitude combustion pressure disturbances associated with liquid rocket resonant (oscillatory) combustion. The work consists of a coordinated experimental and analytical investigation concentrating on relatively large thrust (15,000 to 20,000 lb_f) research engines that are known to exhibit the resonant mode of combustion.

The experimental efforts during the first half of FY 1966 established typical resonant-pressure distributions on the chamber boundaries of a second 11-in.-diameter 20,000 lb_f thrust engine configuration and allowed comparisons with the results (Ref. 1) obtained earlier for a different albeit similar size engine. It is intended that the pressure distributions will be obtained for a third engine of yet a different configuration during the second half of FY 1966. This engine is 18 in. in diameter, uses the injector designated RC 1, and operates at a much lower chamber pressure (100 psia) as well as a propellant mass flux that is lower than the 11-in. engines.

The analytical program continues to be focused on the development of a detonation model of resonant combustion through a consultant contract with V. D. Agosta and S. Z. Burstein.

EXPERIMENTAL PROGRAM

Typical chamber boundary pressure distributions associated with the fully developed resonant mode of combustion exhibited by RMIR injector 7 using the N_2O_4 + 50/50 fuel ($UDMH/N_2H_4$) propellant system have been found and are summarized in Ref. 2. The instantaneous disturbance-to-chamber boundary intersection and the pressure amplitude distribution obtained for this engine are shown in Figs. 1 and 2, respectively, where these results are compared with those obtained earlier for RMIR injector 5 using the so-called Corporal propellants. While no attempt will be made here to discuss the quantitative dissimilarities between the results for the two engines, it is believed that these differences are the result of the particular distribution of energy and mass sources available to the pressure wave in the respective combustion systems. It is noted that both engine configurations used the same 11-in.-diameter chamber/nozzle hardware and a steady state chamber pressure of 300 psia; therefore, the only significant differences between the configurations were the injectors and propellants used.

The qualitative similarities in the resonant characteristics exhibited by either engine may be summarized as:

1. A single disturbance rotates about the combustion chamber axis with an average velocity that is supersonic with respect to a combustion gas mean sonic velocity based on steady state experimental performance. The Mach number obtained is about 1.8.

   The time of complete rotation, as observed at the chamber boundaries, is essentially identical at all locations on the injector face and wall for given engine operating conditions (i.e., during any particular engine firing).

2. The wave-to-chamber wall intersection (Fig. 1) curves in the direction of wave rotation with the nozzle end of the intersection leading the injector end. The wave-to-injector face intersection is nonradial and extends into the central area of the face, although the definition of the intersection (on the pressure records) is poor in this area. It is noted that the intersection curves "steepen" markedly in the proximity of the face and wall boundary junction (i.e., the "corner" of the chamber).

3. The peak boundary pressure amplitude of the disturbance varies axially and radially (Fig. 2), the greatest amplitudes being exhibited near the injector end of the chamber wall and in the outer half radius of the injector face. Note that these peak amplitudes also occur near the "corner" of the combustion volume.

4. The wave form of the disturbance (depicted in the upper right hand portion of Fig. 2), particularly at locations near the injector end of the chamber, exhibit a steep-frontedness (believed to be less than 3 μsec rise time) that is characteristic of shock waves.

As a result of these observed characteristics, an artist's conception of this mode of rocket combustion has been made and is shown in Fig. 3. This drawing is a pictorial representation of the "rotating detonation-like wave" concept mentioned earlier. While the picture attempts to show the complete distribution of the disturbance throughout the combustion and nozzle volume, the actual combustion driven portion of the disturbance is apparently concentrated near the "corner" of the chamber. This observation leads to the description of this portion of the disturbance as a rotating "ball of fire," which was discussed in Ref. 1.

Large variations in the disturbance peak pressure amplitude and tangential velocity as the pressure wave rotates about the chamber circumference have been observed for injector 7. These variations are now under investigation, the results of which may give an insight to a definitive relationship between the high-amplitude, steep-fronted combustion disturbance seen in these engines and the local chamber environment that couples with them.

Physical measurements to find chamber gas motion under resonant conditions have been unsuccessful; primarily from the lack of suitable diagnostic techniques. A water cooled pressure probe is being designed for insertion through the nozzle into the chamber, but this is a difficult task and it is felt that the probe approach will require considerable development.

From a qualitative standpoint another technique has shown some promise. This technique uses a high-speed movie camera placed behind suitable protective shielding on the center-line of the exhaust jet approximately 18 in. downstream of the nozzle exit. The camera can be focused at a plane anywhere between the injector and nozzle exit, but has a depth of focus several inches in either direction from this focal plane. Film speeds of 3000 frames/sec have shown the rotative motion of the combustion disturbance. Further experimentation with photographic techniques is planned.

The procurement and fabrication necessary for test stand revisions for the operation of RC injector 1 with the 18-in.-diameter engine are complete. The stand revision and experimental program for this engine are now expected to start during the second half of FY 1966.

ANALYTICAL PROGRAM

An attempt is being made to analytically describe the sustaining mechanism for the rotating detonation-like wave. It is assumed that the combustion process, originally operating under steady-state conditions, is disturbed by a wave (e.g., from a bomb). A short time later, the combustion process will react to the disturbance, and the object is to discover under what conditions the wave can be sustained by the resulting time-dependent release of mass and energy into the gas phase.

To specify the conditions at any point in the chamber at any instant, the local values of at least five variables are needed: (1) pressure, (2) temperature. (3) velocity, (4) density, and (5) combustion rate. The five simultaneous equations required can be derived using the following laws:

1. Conservation of mass.
2. Conservation of momentum.
3. Conservation of energy.
4. Ideality of the gases and temperature-dependency of the liquid densities.
5. Time and space dependency of combustion rate (this relation is extremely complex, and the generation of a satisfactory approximation to it is a major part of the project).

Using these concepts, the work is divided into six tasks enumerated here along with pertinent comments about the status of the task.

1. Generation of the "wave equations" in three dimensions – Task done.

2. Finding the axial droplet distribution from a one-dimensional nonoscillatory aerothermochemical analysis – A computer program has been written and is now being used in the resonant combustion program.

3. Finding the radial and tangential droplet distribution from the injector geometry– Data for the mass flux and mixture ratio distribution produced by injector RC 1 have been obtained using the nonreactive spray properties of the individual elements.

4. Finding the relaxation time from a nonsteady droplet evaporation analysis and a diffusion analysis of the evaporated fuel vapor through the film surrounding the droplet – Work in progress.

5. From items 2, 3, and 4, calculation of the excess mass release caused by the wave – Work in progress.

6. Applying item 5 to the wave dynamic equations of item i and solving numerically – To be started.

   This presents a formidable mathematical problem whose solution would be a major advance in combustion theory.

PARTICIPATION IN MEETINGS AND SYMPOSIA

The following meetings were attended:

1. ICRPG 7th Liquid Propulsion Symposium, Denver, Colorado, October 19-21. Presented paper (Ref. 1).

2. ICRPG 2nd Combustion Instability Meeting, El Segundo, California, November 1-5 (session chairman).

3. Symposium on Hypergolic Ignition at Altitude, Lockheed Missile and Space Company, November 12-13.

4. Member of ICRPG Working Group on Combustion Instability.

5. Member of Steering Committee for Design Criteria Project (NASA Contract with A. D. Little).

REPORTING

The following progress was made on reports:

1. Reference 1, published.

2. Reference 2, in production.

3. Rupe, J. H., An Experimental Correlation of the Nonreaction Properties of Injection Schemes and Combustion Effects in a Liquid-Propellant Rocket Engine, Part I: The Application of Nonreactive Spray Properties to Rocket Motor Injector Design, JPL TR 32-255, July 15, 1965.

4. Clayton, R. M. and Rupe, J. H., An Experimental Correlation of the Nonreactive Properties of Injection Schemes and Combustion Effects in a Liquid-Propellant Rocket Engine, Part VI: The Relation Between the Starting Transient and Injection Hydraulics, JPL TR 32-255, October 29, 1965.

5. Rupe, J. H., An Experimental Correlation of the Nonreactive Properties of Injection Schemes and Combustion Effects in a Liquid-Propellant Rocket Engine, Part V: On the Influence of Vanes on Combustion and Combustion Stability, JPL TR 32-255 (in draft).

6. Clayton, R. M., Rupe, J. H., and Gerbracht, F. G., An Experimental Correlation of the Nonreactive Properties of Injection Schemes and Combustion Effects in a Liquid-Propellant Rocket Engine, Part 11: On Experimental Apparatus and Techniques, JPL TR 32-255 (in draft).

7. Performance Evaluation of RC injector 1 (in draft, to be published as JPL TR).

8. Sotter, J. G., an interoffice memorandum on resonant combustion to Clayton, Dipprey, Flandro, and Rupe, July 15, 1965.

REFERENCES

1. Clayton, R. M., and Rogero, R. S., Experimental Measurements on a Rotating Detonation-Like Wave Observed During Liquid Rocket Resonant Combustion, JPL TR 32-788, August 15, 1965.

2. JPL SPS 37-36, Vol. IV, December 31, 1965.

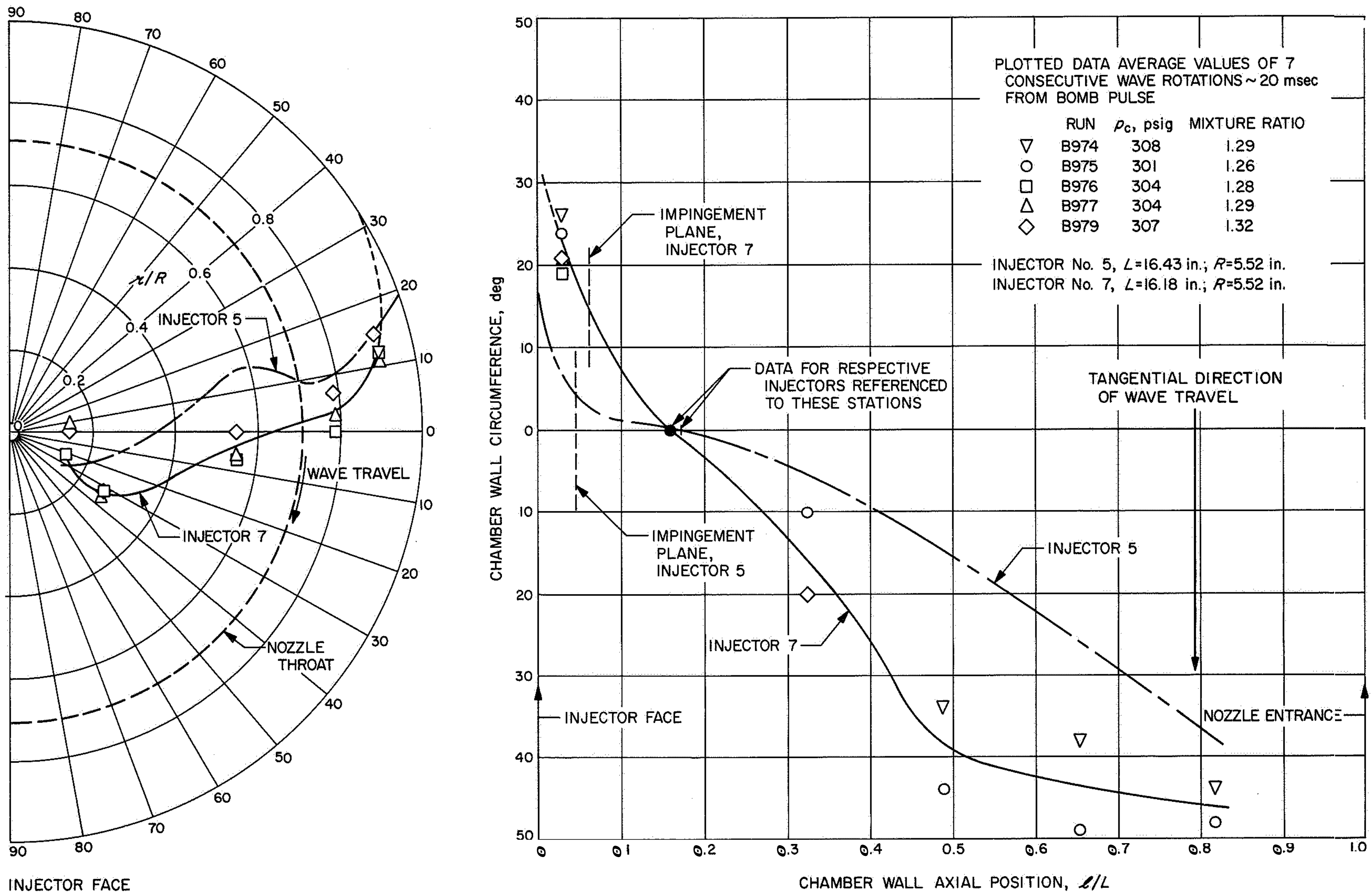


Fig. 1. Intersection of resonant combustion wave with chamber boundary, RMIR injector 7 with N_2O_4 + 50/50 fuel (UDMH/N_2H_4)

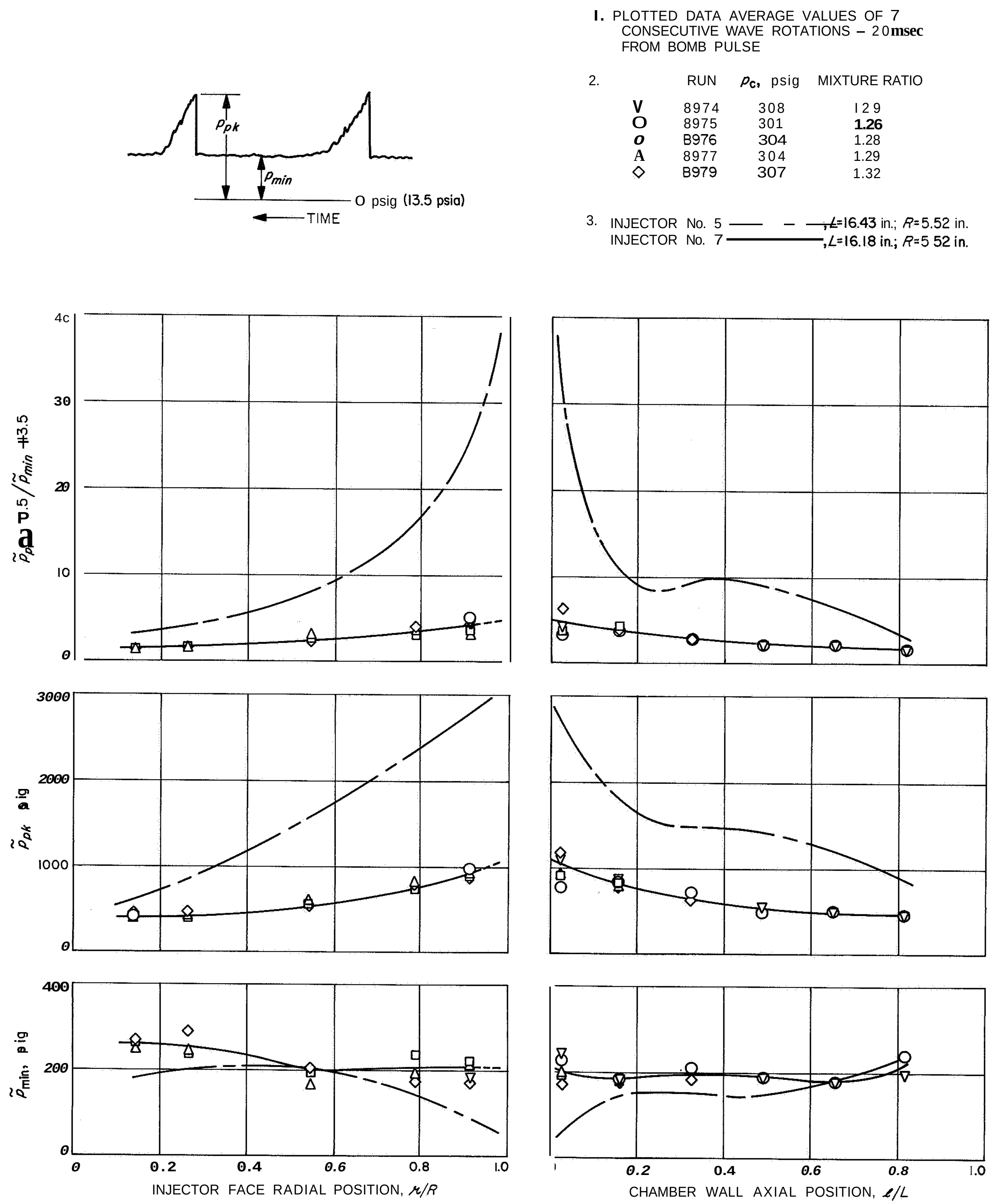
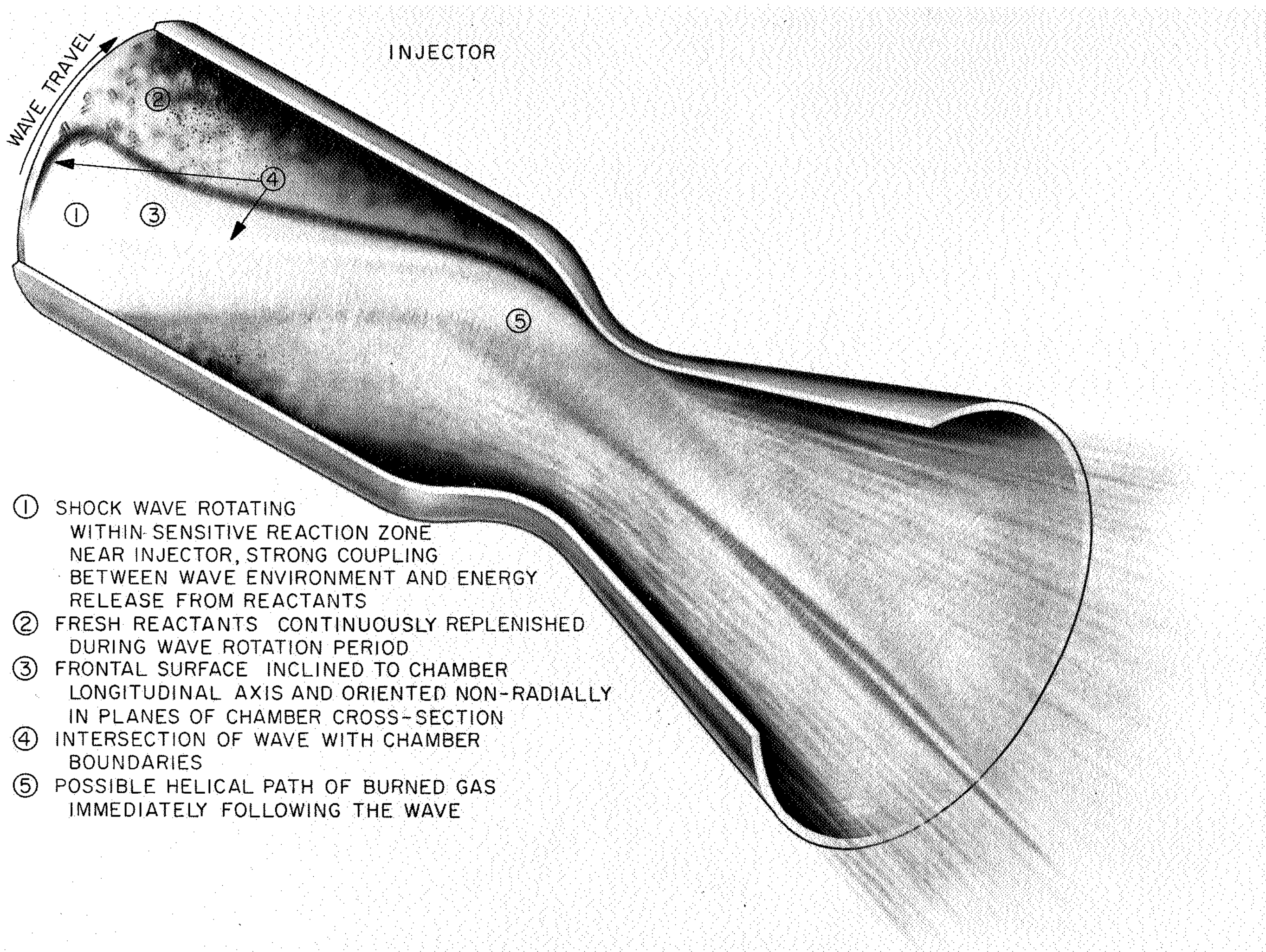


Fig. 2. Resonant combustion pressure amplitude vs chamber boundary position RMIR injector 7 with N_2O_4 + 50/50 fuel (UDMH/N_2H_4)



Fig, 3. Artist's conception of detonation-like wave disturbance

3

ATOMIZATION AND INJECTOR HYDRAULICS
NASA Work Unit 128-31-06-02-55
JPL 328-10701-1-3840
George I. Jaivin

3BJECTIVE

The objective of this work unit is to obtain a quantitative determination of the pertinent hydrodynamic properties of injection schemes and their relationship to the characteristics of the resulting sprays to better understand the combustion phenomena occurring in a liquid propellant rocket engine.

ACTIVITIES

The colorimetric apparatus, a device capable of measuring the local mixture ratio of spray samples formed by miscible fluids, was evaluated during the last reporting period. As part of an appraisal that was made of the system's capabilities, a test series was conducted to correlate the data obtained from two identical flow configurations in which miscible and immiscible test fluids were used. It was found that virtually identical results were obtained in the two cases, therefore corroborating the evidence of an earlier investigation and enhancing the confidence in the present system.

A Space Program Summary (SPS 37-35) was written about the effect of absolute density of nonreactive fluids used in the spray sampling technique as reported in the last semiannual report.

To try and extend the usefulness and applicability of the spray data already obtained, a test fixture was built to investigate the effects of orifice centerline misalignment on the resulting mass and mixture ratio distributions. The design of the test hardware made it possible to reproducibly and accurately move the orifices known distances; therefore, by use of the existing spray sampling equipment quantitative measurements could be made of the changes that occurred in the spray properties. Data was obtained using this procedure, but it has not yet been reduced or analyzed.

GAS SIDE BOUNDARY PHENOMENA

NASA Work Unit 128-31-06-03-55
JPL 328-10801-1-3840
R. W. Rowley

3BJECTIVE

The long-range objective of this work unit is to correlate local heat transfer ınd local erosion in the combustion region of liquid rocket engines with local charac- eristics of the nonuniform freestream flow produced by typical propellant injection nethods. The objective for FY 1966 is to complete the correlation of heat transfer ınd local spray properties at atmospheric pressure in a methanol-nitric acid ɜnclosed combustor and to extend this correlation to local heat transfer measurements n a rocket engine using the same injector and propellant combination but operating at ıpproximately 100 psia chamber pressure.

ΞNCLOSED COMBUSTOR

The enclosed combustor has been moved and the test cell modified to accom- nodate an added experiment being conducted as part of another work unit. Figure 1 hows the combustor with the probe support apparatus protruding from the side.

Results of heat transfer tests conducted with this apparatus, using a flat faced ›robe placed normal to the resultant momentum line of a spray produced by impinging treams of nitric acid and methanol, show that while local heat flux is related to the ocal mass flow rate, the heat transfkr process is dominated by impingement of nconsumed droplets on the face of the probe. Figure 2 shows the heat transfer rate n both a burning spray and in an unignited spray of the same flow rate. In the latter ase, heat is generated only by liquid phase reactions between fuel and oxidizer. ɩlso shown is the local spray mass flow rate, as determined with nonreacting fluids.

Starting the first of the year, tests will be conducted to define the rate of ɩquid phase reaction in the acid/methanol system and to measure droplet tempera- ires in both the burning and the unignited sprays.

'HRUST CHAMBER TESTS

Thrust chamber tests scheduled to be performed in the first half of FY 1966 ave been postponed until the second half to allow completion of the test cell modifi- ation and some added tests using the enclosed combustor. Preliminary design of ıe instrumented thrust chamber has been started. Technician support continues at low level and is the pacing factor in the experimental program. Also, engineering ıanpower was reduced during the first quarter of FY 1966 by a temporary assignment › the Voyager project.

ELATED EFFORTS

The digital data logging program used by the Data Analysis Facility for ɜcording test results on the PDP-4 computer has been modified to improve both the ›gging process and later data processing (engineering units conversion and heat flux ılculation) by the IBM 7094.

A technical report describing previous work on injector related thrust chamber erosion is in draft. The Fall meeting of the Western States Section of the Combustion Institute at Santa Barbara, California was attended on October 25, 1965.

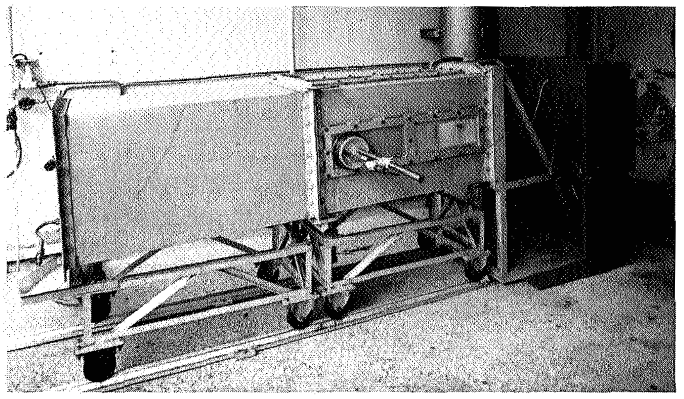


Fig. 1. Enclosed combustor

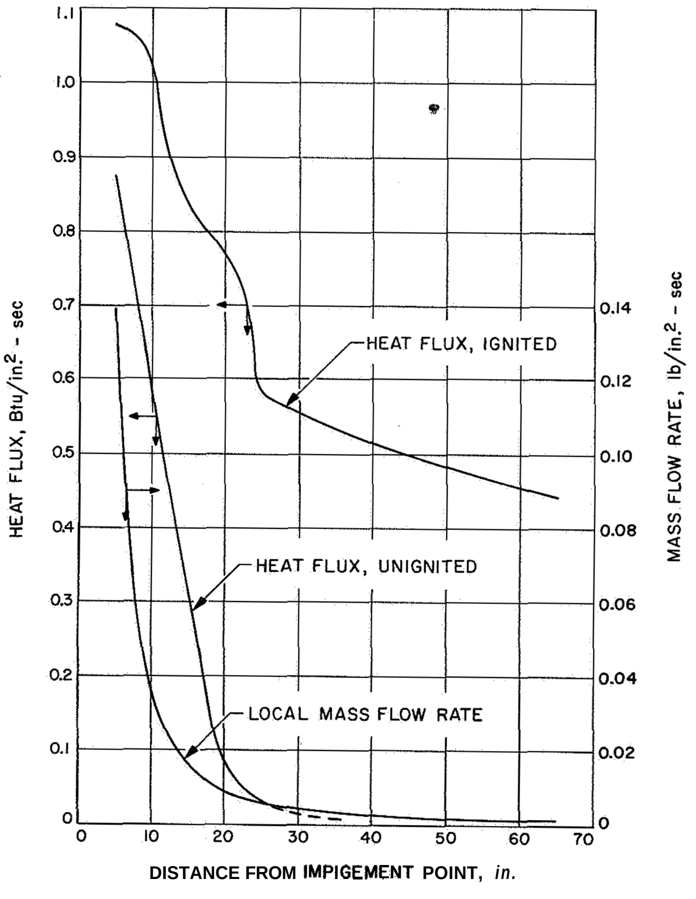


Fig. 2. Heat flux and flow rate along spray resultant momentum line

REACTION MECHANISMS IN SPRAYS

NASA Work Unit 128-31-06-04-55

JPL 328-10901-1-3840

J. W. Woodward

OBJECTIVE

Liquid propellant rocket engine combustion is, to a large extent, controlled by the physical processes that are related to the injection scheme. In particular, the heat transfer from the reactants to the injected fluids and the consequent vaporization as well as "liquid phase" reactions (when they occur) are considered dominant parameters. The finding of their characteristics and their correlations with the injection scheme are essential to the logical, successful development of the high-performance, stable, reliable, and compatible, propulsion systems that are required in future spacecraft. A series of experiments has been planned to measure the spatial distribution of the local fuel mixture ratio produced by a single pair of unlike-impinging streams in a combustion chamber. These plans are described in a contribution to JPL SPS 37-36, Vol. IV.

PROGRESS

Work on this project started in April 1965; the months of April, May, and June were used for familiarization with the problem, the rough development of the plans for the experiment, and a survey of the mass spectrometers available for use on the project. Work completed during the first half of the FY 1966 includes a computer study to demonstrate the feasibility of using a mass spectrometer to analyze combustion gas samples from a rocket combustion chamber, procurement of a Jarrell Ash Quadrupole Mass Spectrometer, procurement of propellant tanks, and design of the combustion chamber and sampling probe.

FUTURE PLANS

Plans for the next 6 mo include calibration of the mass spectrometer, assembly of the test equipment, development of data logging computer routines for the mass spectrometer output, development of computer routines for the data reduction, and the starting of experimental runs.

HETEROGENEOUS COMBUSTION
NASA Work Unit 128-31-06-05-55
JPL 328-11101-2-3840

R. A. Rhein

OBJECTIVE

The objective of this program is to study the chemical reactions between high energy rocket fuels and oxidizers to learn about their ignition mechanisms.

The reaction between oxygen difluoride and diborane will be studied first, and other propellant combinations that are regarded as particularly promising for spacecraft applications will be studied later.

To study these reactions, a chemistry laboratory has been set up; a photograph of the laboratory is shown in Fig. 1. An all-purpose vacuum rack was built, and is now operating; a gas chromatograph, infrared spectrometer, an oven, fume hoods, and other facilities have been set up and are operating. The necessary facilities for handling fluorine and oxygen difluoride have been installed.

During this report period, the author reported on previous work in two publications. One was "Ignition of Ultra-Fine Powdered Boron in Air, Nitrogen, Carbon Dioxide and in Mixtures of Nitrogen and Carbon Dioxide," in JPL SPS 37-36, Vol. IV; the other was "The Ignition and Combustion of Powdered Metals in the Atmospheres of Venus, Earth, and Mars," to be published in Astronautics Acta and will be distributed as JPL TR 32-724.

R, A. Rhein has been managing contract NAS 7-376, "A Theoretical Investigation of Liquid B," by Aerojet-General Corporation. Aerojet has succeeded in showing that there are, indeed, theoretical structures for a stable liquid "B"; Aerojet is now studying various possible methods of synthesis.

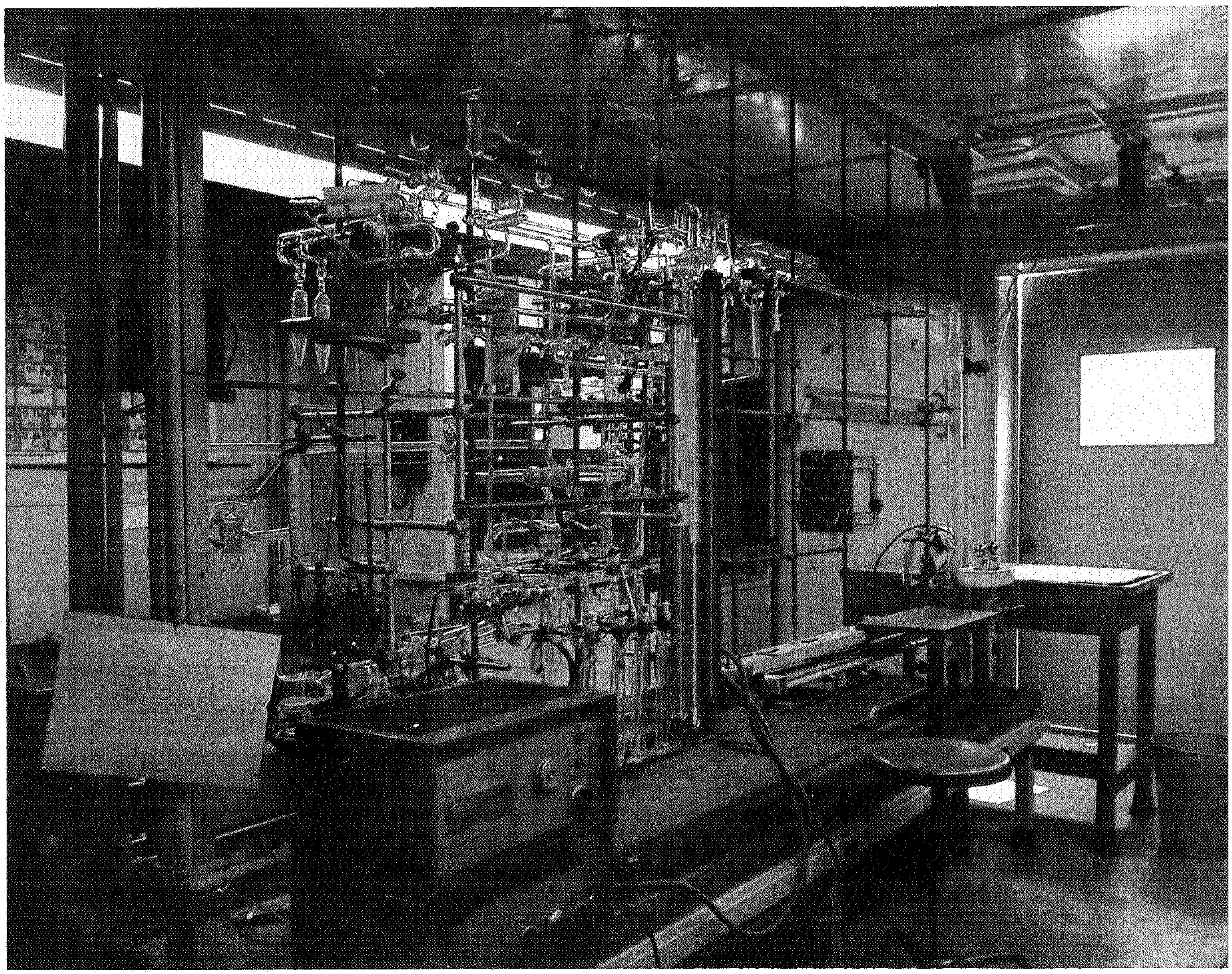


Fig. 1. Laboratory for study of reaction between oxygen difluoride and diborane and other propellant combinations

REFRACTORY METAL COATINGS EVALUATION

NASA Work Unit 128-31-06-06-55
JPL 328-11201-2-3840
W. H. Tyler

OBJECTIVE

This program is to evaluate protective coatings for refractory materials intended to be used in liquid propellant rocket thrust chambers and that are produced by Illinois Institute of Technology Research Institute (IITRI) under NASA Contract No. NAS 7-113.

APPARATUS AND METHOD

The injector used in this test program, designated the ALPS Mod. IV, has been characterized in terms of propellant mass, mixture ratio, and chamber wall heat flux distributions under the ALPS program (Contract NAS 7-100, Task 731-12-03-02-55), and is particularly appropriate for this task because it exhibits low, uniform erosion with materials constructed from pyrolytic graphite or Refrasil-phenolic.

The test injector assembly is clamped to a water-cooled chamber section and test nozzle insert assembly as shown in Fig. 1. The nozzle insert assembly contains the IITRI test insert with a molded graphite structural and thermal backup, which is wedged into two molded pieces of silica fabric and phenolic resin material. These parts are glued together and then overwrapped with fiberglass. This overwrapped assembly is slipped into a steel retainer for mounting against the water-cooled combustion chamber.

Initial tests were conducted with reduced combustion gas temperatures, followed by increased gas temperature testing of materials that successfully passed the lower temperature tests. To obtain the reduced test gas temperature of about 3500°F, the injector was tested with hydrazine and nitrogen tetroxide at a mixture ratio ($\dot{w}_o/\dot{w}_f$) of 0.8, and with a 15% (by weight) water diluent added to the fuel. For the increased gas temperature of about 4000°F, the injector was tested with neat hydrazine and nitrogen tetroxide at a mixture ratio of 0.83.

TEST RESULTS

A total of 20 tests was conducted. This total includes both heavy-weight molybdenum nozzle checkout tests and tests of two IITRI insert assemblies. Two different nozzle inserts samples were tested. One insert was a plasma-sprayed hafnium oxide-graded composite on a tungsten base, and the other was a hafnium-tantalum clad tungsten-tantalum alloy. Besides these two inserts, two other inserts were also assembled with the structural and thermal backup components and over-wrapped with fiberglass, but were not tested.

Each of the inserts tested accumulated over 17 min of firing time at the reduced gas temperature (3500°F) with little or no change of throat diameter. For these tests, the chamber pressure records were flat during the run, showing no erosion had occurred.

The same two inserts were then tested at the higher gas temperatures (4000°F) The plasma-sprayed graded-composite survived two, 10-sec tests with little or no adverse effects, but started to erode significantly after 950 sec of a continuous firing, with complete burn-through occurring 17 sec later. The hafnium-tantalum clad material gave about the same results when it was fired with the 4000°F gas temperature conditions. It was essentially not affected by a 10 sec test but started to erode slowly after 850 sec of continuous firing with burn-through occurring after 940 sec of test.

The funding for this program has now been completely spent. One more test is planned using a state-of-the-art coated molybdenum nozzle insert for comparison with the inserts already tested. Two other insert assemblies and two free standing radiation cooled nozzles that were not tested have been returned to the contract technical manager. Future testing of new nozzle inserts samples and radiation-cooled nozzles will be done by a contractor using this test hardware.

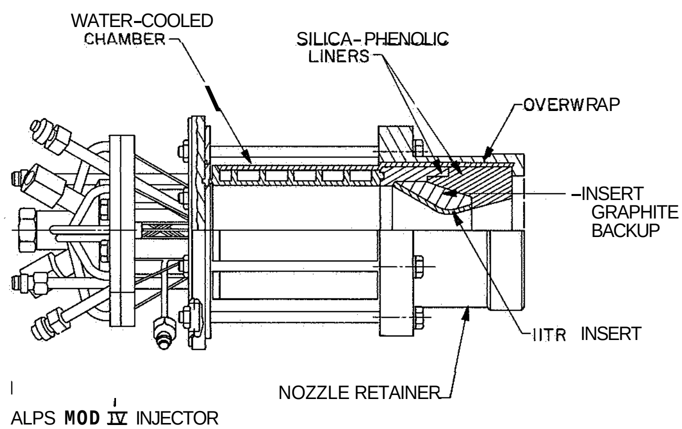


Fig. 1. Engine assembly, IIT RI insert test

SOLID PROPULSION TECHNOLOGY (128-32)

ADVANCED TECHNOLOGY CONTRACT MANAGEMENT
NASA Work Unit 128-32-01-01-55
JPL 328-20101-2-3810
Winston Gin

OBJECTIVE

The objective of this continuing task is to provide technical management for contracts and grants that are under the program management of NASA headquarters. The specific contracts and grants are matched with the technical interests and competence at JPL. Sponsorship of these grants and contracts emanates from Codes RPM and RPS at headquarters,

STATUS

The following contracts and grants are being managed under this task:

"Upper Stage Applications of Advanced Solid and Hybrid Propellant Motors," NAS 7-375 at Lockheed Missiles and Space Company,

"Hybrid and High Energy Solid Motors for Upper Stage Applications," NAS 7-374 at Douglas Aircraft's Missiles and Space Systems Division.

"Ignition and Combustion of Metal Wires," NAS 7-353 at United Aircraft Research Laboratories.

"Low Pressure Ignition and Combustion," NsG 200-60 at Princeton University,

"Pre-Ignition and Ignition of Metals," NsG-641 at Princeton University.

"Chemistry of Solid Propellant Combustion," at University of Utah.

"Synthesis of Nitramine Polymers for Solid Propellants," NAS 7-293 at Rocketdyne.

"Uncoated SPO Propellant Development," NASw 1130 at Thiokol, Elkton Division.

"Study of Metal Combustion," WO 3033 at the Naval Ordnance Test Station.

"Ablative Nozzle Throat Material Evaluation," NAS 7-425, at the United Technology Center.

During this Report period, work has completed on "Studies on Ignition and 'lame Propagation in Solid Propellants," NAS 7-329 at the United Technology Center nd the preliminary draft of the final report is expected. Work has completed on Igniter Heat Transfer Studies," NAS 7-302 at the United Technology Center and the final report has been distributed. No follow-on to this project is in being because of shortage of funds and the departure of the principal investigators from UTC. However, some uncompleted work by UTC on this contract has been brought in-house and is being performed by JPL. Work has completed on "High Altitude Solid Motor Nozzle Materials Analysis," NAS 7-397, at the United Technology Center and the draft of the final report has been technically reviewed.

During the next report period, a major redirection of effort on NAS 7-293 is anticipated because of the technically unfruitful results to date; contracts on light metal hydride propellant research, propellant detonation hazards, and fluid controlled motor research will be funded by headquarters and managed by JPL personnel

ROCKET MATERIALS AND COMPONENTS DEVELOPMENT

NASA Work Unit 128-32-03-01-55
JPL 328-20201-2-3810

Richard L. Bailey

OBJECTIVE

Evaluate materials for solid rocket motor components such as nozzles, chamber, and insulation and establish the applicability of advanced materials, fabrication techniques, and component design to high performance of solid rocket motors.

STATUS

The simulated high altitude tests with beryllium propellant have been completed. This program was conducted as a cooperative effort with the Rocket Propulsion Laboratory, Edwards Air Force Base. All testing was carried out in Test Cell T-3 at the Arnold Engineering Development Center, Tullahoma, Tennessee. The RPL tests consisted of four Atlantic Research Corp. motors loaded with 50 lb each of Arcocel 333E (2) and 365 (2), and seven RPL BATES motors loaded with 70 lb each of Arcocel 333E. These propellants all contained beryllium propellant. The RPL firings used nozzles of expansion ratios of 40:1 and 100:1 that were all tested at a chamber pressure of 750 psia.

The JPL portion of the program consisted of testing 20 motors with Thiokol Chemical Corp, beryllium and aluminum propellants and Atlantic Research Corp. beryllium and aluminum propellants. These tests used the RPL BATES motor configuration, but a JPL nozzle design was used (Fig. 1). All 20 firings were made with a nozzle expansion ratio of 50:1. The chamber pressure was varied from test to test to evaluate the effect of chamber pressure on overall motor performance. Aluminum analogs of the beryllium propellants were tested for a reference performance. Table 1 summarizes the JPL tests,

Table 1. Test results

Propellant	Chamber pressure, maximum psia	Number of tests
Arcocel 319 BRG (Be)	Varied from 250 to 700	6
Arcocel 321 BR (Al)	Varied from 300 to 1000	2
TP-H-1092 (Bl)	Varied from 250 to 700	7
TP-H-3062 (Al)	Varied from 300 to 700	2
TP-H-3135 (Al)	650	2
TP-H-3108 (Bl)	700 (submerged nozzle)	1

The BATES motors were all ignited with a slightly modified SR-12-1 igniter (Fig. 1). The SR-12-1 igniter basket was enlarged internally to hold 68 g of Alclo pellets. Ignition was successful on every run, and all the motors tested successfully.

The beryllium motors showed a large increase in performance over the aluminum motors at the same chamber pressure. Also, the Thiokol beryllium propellant showed higher performance than the Atlantic Research beryllium propellant.

A camera box has been designed that will allow the use of large, high-speed cameras for photographing nozzle throats during firing. Preliminary tests with small 5 x 6 motors showed that the nozzle throat could be seen in the movies. Because further tests are required to evaluate various film speeds and filters, a special camera box was designed for use with longer-burning time motors. The box will be water jacketed and pressurized internally with an inert atmosphere to keep out exhaust particles that may leak through the seals. The box is now out for fabrication.

To evaluate materials at high chamber pressures and long burning times, an uncured propellant end burner has been designed, fabricated, and tested. This motor (Fig. 1) can test insulation and throat materials up to 500-psi chamber pressure for about 30 sec. Ultimately, materials can be tested up to 1000-psi chamber pressure for over 100 sec with throat size's up to 4 in. in diameter.

For the first firing, the chamber and aft closure were insulated with GTR-V-52 rubber. A JPL-developed nongelling polyurethane/aluminized propellant was used for the test. The motor fired satisfactorily for a total of 27 sec. A constant pressure of 700 psi was obtained for this time with a National Carbon JTA graphite throat insert. Several materials have been ordered for further testing with the motor.

Evaluation of the lightweight carbon and silica phenolic systems has started. These systems are carbon or silica paper impregnated with a straight or modified phenolic resin and can be tape-wrapped the same as fabrics. A tape-wrapped SR-12-1 submerged nozzle was tested, which consisted of a Fiberite carbon paper material (MXC-113) nozzle body and a Graphitite GX throat insert. Figure 2 shows a view of the nozzle before firing. The nozzle fired successfully for the test duration of approximately 20 sec. The motor performance compared very well to firings made with a standard SR-12-1 nozzle. Figure 3 shows a view of the nozzle after firing. The carbon paper portion of the nozzle was deeply gouged but held together during the firing, and appeared to have no bad effect on the motor performance. This nozzle provided a weight savings of 35 to 40% over a similar nozzle fabricated with a normal carbon fabric/phenolic system.

The Hercules fabricated, MSFC sponsored hot gas valve was tested successfully on the Air Force RPL 100-in.-diameter char motor during December. The test 'was monitored for NASA/MSFC by JPL. The valve performed ten full duty cycles of 0.6 sec on and 4 sec off during the first 40 sec of a 100-sec motor firing time. It also operated successfully for one full cycle just before shutdown. The nozzle appeared to be in very good condition after the firing.

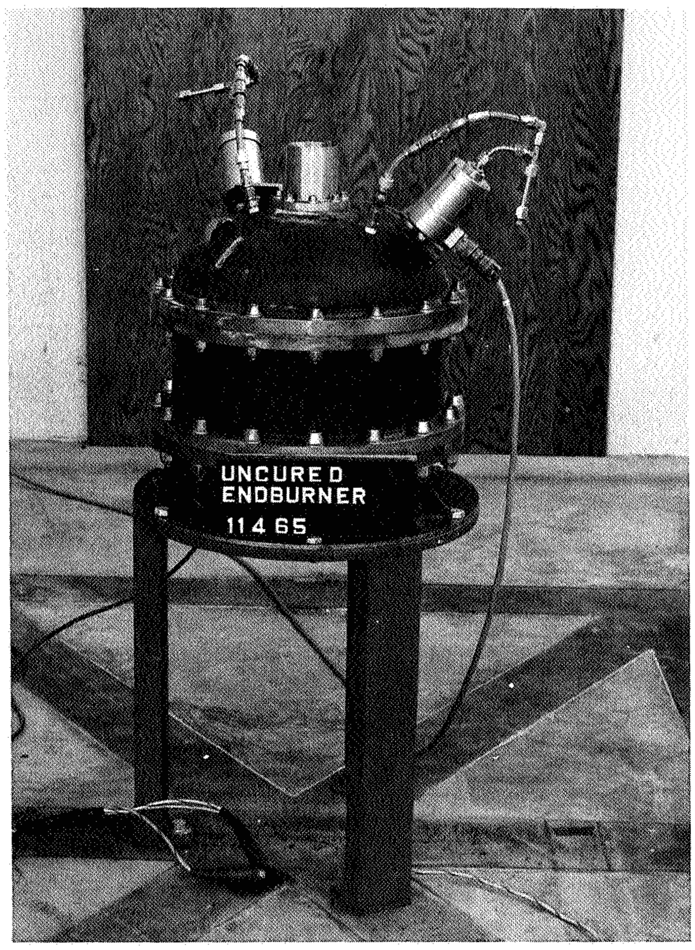


Fig. 1. Uncured endburner before firing

Fig. 2. Carbon paper nozzle before firing

Fig. 3. Carbon paper nozzle after firing

RHEOLOGICAL PROPERTIES OF PROPELLANTS

NASA Work Unit 128-32-05-02-55
JPL 328-20301-1-3820

R. F. Fedors
B. G. Moser
W. D. Hutchinson

OBJECTIVE

The objective of this task is to evolve and substantiate a theory ofviscoelastic behavior that will permit predicting the response of a solid propellant to a generalized stress-fire temperature field.

ULTIMATE PROPERTIES IN UNJAXIAL TENSION

In the previous summary, it was shown that the stress-strain relationship ɔased on the inverse Langevin function gave a good representation for the ultimate properties of gum elastomers; this has been confirmed with data that have recently secome available on more elastomers. To expedite the application of this stress-strain relation, values of σ and ϵ for selected values of n have been computed and ɪre available in both tabular and graphical form. It is intended to publish the com-suted data in the open literature.

Based on the applicability of this stress-strain relationship to provide a :easonable fit to experimental break data, it has been shown that the upturn in the 'ailure envelope (i.e., the maximum value of the extension ratio-at-break) $(\lambda_b)_{max}$:an be related to the concentration of effective chains per unit volume of gel, ν'_e, by

$$(\lambda_b)_{max} \geq \left[\frac{N_o(1 + S)M}{(1 + S)M\nu'_e + a\rho}\right]^{1/2} \tag{1}$$

vhere N_o is the concentration of statistical units per unit volume of effective network hain, S is the sol fraction, M is the molecular weight of the primary molecules after rosslinking, ρ is the polymer density, and a is a parameter that can assume values f 1 or 2 depending on how the free chain end fraction in the gel is evaluated. Eq (1) vas derived where the molecules have a random size distribution, which is usual in ractice. For other size distributions, more appropriate equations can be developed. 'or small values of S and for large ν'_e, conditions that are satisfied for well vulcan-zed elastomers,

$$(\lambda_b)_{max} \approx \left(\frac{N_o}{\nu_e}\right)^{1/2} \tag{2}$$

which has been found to provide a good representation of experimental data. Therefore, the inverse Langevin stress-strain relationship, in conjunction with Eq (2), allows a prediction of the approximate shape and location of the failure envelope from a knowledge of ν_e and n or N_o. As a first approximation, $N_o \approx 4.5 \times 10^{-3}$ moles cm-3.

When n is small (i.e., n < 6), the inverse Langevin function is not exact enough, and a better representation for stress-strain behavior is provided by one based on a series distribution formula. Work has been started on computing values of σ and ϵ for various values of n using the series distribution formula.

CARBOXY ELASTOMERS

Uniaxial stress-strain data for the carboxylic elastomers have been obtained as a function of rate and temperature. Also, stress relaxation runs have been completed; an apparatus is now being constructed to carry out measurements of creep behavior as a function of temperature. Measurements of compliance as a function of both temperature and frequency are now being carried out by Professor E. Fitzgerald at Johns Hopkins University.

Preliminary evaluation of the ultimate property data for these elastomers has definitely established that the prior theory of the strength of elastomers containing ionic crosslinks is incorrect. A new theory has been developed that seems to fit experimental data.

FILLED SYSTEMS

Studies are continuing on model systems for propellants. Styrene butadiene rubber (SBR) and silicone rubber filled with glass beads to approximately 40 and 50 percent volume respectively, have been tested uniaxially for ultimate properties. Experiments designed to assess the role of dewetting on stress-strain behavior including the ultimate properties are underway. Although considerably altering the shape of the stress-strain curve, indications are that dewetting has no appreciable effect on the values of stress and strain at break.

The degree of crosslinking for both SBR and silicone composites is being redetermined from data obtained on uniaxial compression on swollen disks.

FOAMS

Rings of various sizes have been fabricated. The deformation of ring specimens will be investigated photographically to calibrate the movement of the testing machine crosshead to the deformation of the ring. This study will also show whether the ultimate properties depend on specimen size.

RHEOLOGY OF SLURRIES

Work has continued over the last 6 mo on the phenomenon of particle-to-particle attractive forces coming from London-van der Waals attractive forces. As was pointed out in the last Semiannual Progress Report, these relative attractive forces are expressed as a function of the parameter ϕ_m (where ϕ_m = (volume solids) (total volume)). It was pointed out that ϕ_m is a function of particle size. It has been further determined that the surface state or surface energy of the particles influences ϕ_m. That is, we have found that the load a bed of small particles or dust can support without collapsing depends on the size of the particles and on the energy condition of their surface (Fig. 1 shows this). An equal weight of powdered aluminum, of identical particle size ~ 11 micron but with different surface energies, or particle-particle attraction, is shown to occupy different volumes in the bottles. The uncoated particles in the left-hand bottle occupy a large volume and are, therefore, very loosely packed. The particles in the middle bottle have been coated with a monolayer of alcohol 1 atom thick and are packed more tightly. The right-hand bottle has been coated with a monolayer of asolectin, an effective surfactant, and is packed very tightly. The expected load bearing capacities of the three particle beds are shown by the bar diagram at the bottom of Fig. 1. As expected, the loosely packed bed on the left will not support as great a load as the tightly packed bed on the right.

BURNING RATES

An effective surfactant results in a lower burning rate of composite solid propellant. This is believed caused by the lower surface energy and consequent greater degree of dispersion of the oxidizer particle. Therefore, one would believe that if the oxidizer particles were in a high surface energy state, a very high burning rate should result. This is shown in Fig. 2 where a burning rate of 60 in./sec was measured. The fuel used is a USP mineral oil — a system that can not be cured. All polymer systems that could be suitably cured to a propellant are also autophobic to a small degree. That is, they are more or less weakly effective surfactants. This phenomenon is shown in Fig. 2 with poly (propylene oxide), PPO, the backbone of polyurethane propellants.

FINITE DEFORMATION OF ELASTOMERS

The strain energy functions of both natural rubber and the SiO_2 filled poly-dimethyl siloxane polymer, Silastic 950 u, have been experimentally found. The strain energy function of natural rubber has been confirmed to be of the form

$$W = C_1(I_1 - 3) + f(I_2 - 3) \tag{3}$$

previously reported for this material by Rivlin and Saunders. In Eq (3), C_1 is a constant, f is a function, and the quantities I_1 and I_2 are invariants of the tensor defining the deformation of a cube into a rectangular parallelopiped. From the mathematical theory of finite deformation, these invariants are given by:

$$I_1 = g^{rs}G_{rs} = \lambda_1^2 + \lambda_2^2 + \lambda_3^2 \text{ and } I_2 = g_{rs}G^{rs} \quad I_3 = \lambda_1^2\lambda_2^2 + \lambda_1^2\lambda_3^2 + \lambda_2^2\lambda_3^2$$

where g^{rs} and g_{rs}, and G^{rs} and G_{rs} are the contravariant and covariant metric tensors of the undeformed and deformed bodies respectively, and I_3 is a third invariant given by the ratios of the values of the determinants of the components of the elements of the metric tensors of the deformed and undeformed bodies (= G/g = $\lambda_1^2\lambda_2^2\lambda_3^2$). For a material such as natural rubber, the invariant I_3 is experimentally indistinguishable from the constant value of unity because the material is virtually incompressible.

The strain energy function found for the Silastic 950 u is of the form, expressed as a power series,

$$W = 25(I_1 - 3) + 1.25(I_1 - 3)^2 + 7.85(I_2 - 3) - 0.253(I_2 - 3)^2 + \quad \ldots$$

Here, no dependence on I3 is seen because Silastic 950 u is, like natural rubber, virtually incompressible.

The experimentally observed strain energy functions of both materials differ from the form predicted by the molecular theory of rubber elasticity. This form is for a compressible material

$$W = K_1(I_1 - 3) - K_2 \ln I_3^{1/2}$$

For an incompressible material the second term would equal zero. It is seen that the second strain invariant does not enter the stored energy function predicted by this theory, which is based on gaussian chain statistics. Other modifications of this theory {taking into account the finite extensibility of the chains and the finite volumes of the chains) do not account even qualitatively for the experimentally observed dependence of the strain energy function upon the invariant I_2. This invariant I_2 has been studied to determine its physical significance.

It can be shown that the invariant I_2 $(= \lambda_1^2 \lambda_2^2 + \lambda_2^2 \lambda_3^2 + \lambda_1^2 \lambda_3^2)$ can be related to the surface area of the rubber sample being deformed, *so* that

$$I_2 = 9(A/A_o)^2 - 2\, I_3^{1/2}\, (I_1 - 6A/A_o)^{1/2}$$

where A and A_o are the surface areas of the deformed and undeformed samples. Differentiating this relation, holding the invariants I_1 and I_3 constant shows that a variation in the invariant I_2 alone corresponds to a deformation in which only the surface area is changed. A sensitivity of the strain energy function to the surface-to-volume ratio is suggested. Experimentalwork is now being made to determine the sensitivity of the strain energy function to the surface-to-volume ratio. The dependence of the invariant I_2 on the surface area should be borne out from these experiment5 being made on uniaxially deformed samples having different ratios of surface-to-volume.

The materials, natural rubber and Silastic 950 u, that have been studied deviate significantly from the perfectly elastic material chosen as models for development of both the mathematical and the molecular theories of finite elasticity. A formulation of butyl rubber, which has been reported to approach perfect elasticity, has been chosen for determining its strain energy function. From these studies it is hoped that a better estimate may be made of the departures of molecular theory of finite elasticity, in not accounting for surface effects or effects involving invariant I_2.

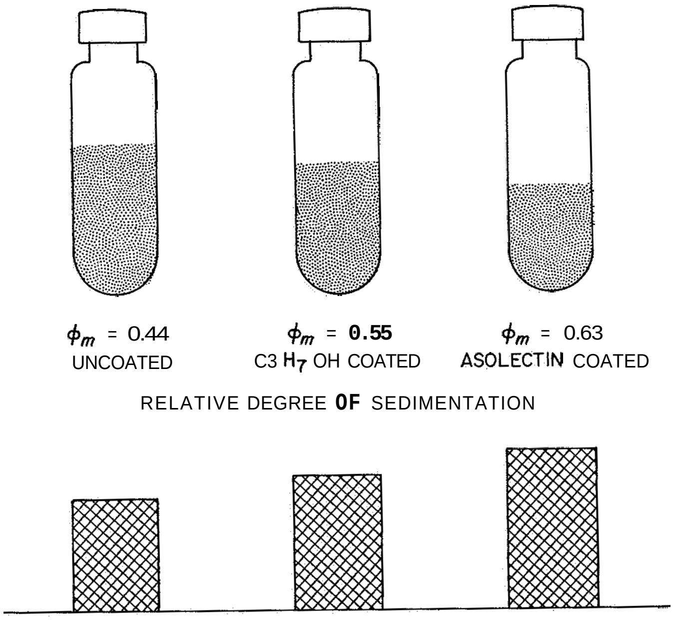


Fig. 1. Load bearing capacity as function of sedimentation

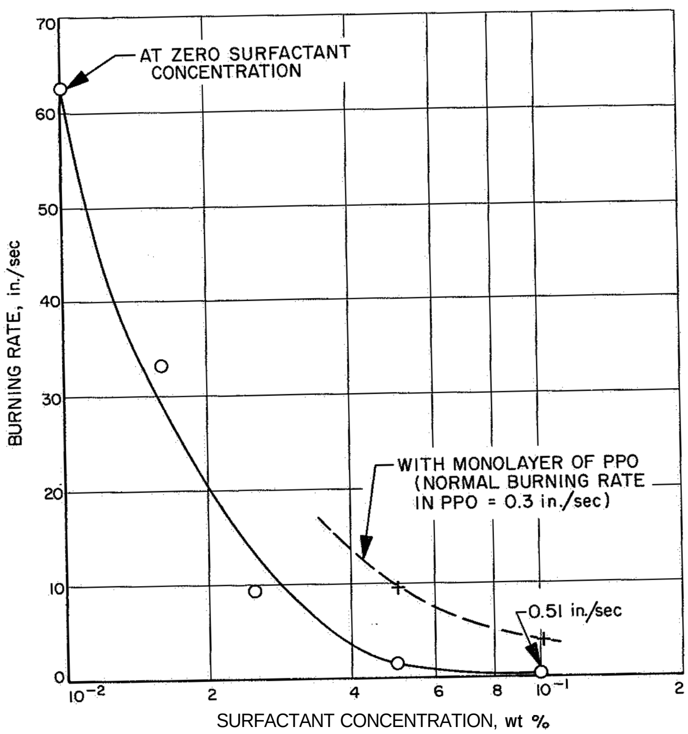


Fig. 2. Burning rate vs surfactant concentration for bimodal AP in USP mineral oil (82 wt% solids)

DEGRADATION MECHANISMS

NASA Work Unit 128-32-05-03-55
JPL 328-20401-1-3820

J. D. Ingham, E. F. Kopka,
G. K. Ostrum, D. D. Lawson

OBJECTIVE

The objective of this work unit is to investigate the molecular structure, chemistry, and degradation mechanisms of polymeric materials to provide a fundamental basis for the development of nondestructive test methods involving chemical changes in polymers and propellants.

URETHANE DEGRADATION

Studies of the thermal degradation at moderate temperatures (80 to 150°C) of poly (propylene oxide),(PPO), reacted with C^{14}-labeled p-tolyl isocyanate, PTI; o-tolyl isocyanate, OTI; and 2,4-tolylene diisocyanate, TDI, have been made. Measurement of the evolution of $C^{14}O_2$ should reflect the rates of scission of the urethane linkages. Previously, the measured rates at 128 and 150°C for PPO-PTI were found to be nearly the same, with a much lower rate at 109°C. More recently, further measurements have been made that prove the observed rate at 150°C and very strongly hint that the measurement at 128°C was wrong. Some of the results obtained are summarized in Table 1. An Arrhenius plot is shown in Fig. 1.

Table 1. Summary of results

Product	Temperature, °C	Rate of C^{14} Evolution, %/hr x 10^5
PPO-PTI	80	1.92
	109	8.4
	128	44.5*
	141	33.0
	150	46.0
PPO-OTI	80	2.29
	109	9.4
	141	33.0
PPO-TDI	110	8.8
	150	51.6

*Wrong, should be ~ 20 x 10^{-5}%/hr.

Two main conclusions are made from this work. First, there is no difference in the rates of $C^{14}O_2$ evolution for urethanes prepared from PPO and either PTI, OTI, or TDI; therefore, the interpretation of degradative studies of TDI polyurethanes is greatly simplified. Second, a linear plot giving an activation energy of 13.7 kcal/mole is obtained between 80 and 150°C; therefore, for this process, it is safe *to* extrapolate to reasonably low temperatures from data obtained from accelerated tests at ~ 150°C.

This work will be extended to try and correlate $C^{14}O_2$ evolution with changes in molecular weight of polyurethanes.

POLYMER NUCLEAR MAGNETIC RESONANCE SPECTROSCOPY STUDIES

In earlier nuclear magnetic resonance (NMR) studies we have found that the F^{19} signals from the trifluoroacetate esters of the secondary hydroxyls of poly (propylene oxide) were doublets caused by the stereoconfiguration of the adjacent end units. The detection of such subtle structural features is basically significant because they influence the reactivity of the terminal group and, therefore, may critically affect polymer degradative processes, synthesis, and processing.

POLY (ALKYLENE OXIDE) POLYMERS

The ditrifluoroacetates of poly (epichlorohydrin) and poly (1,3-butylene oxide) were prepared. The ester of the poly (epichlorohydrin) shows (see Fig. 2) the F^{19} signal as a doublet, which shows that two different types of secondary hydroxyl groups are in the diol. The differences in hydroxyl groups is caused by asymmetric carbons in each monomeric unit with two different diol forms at the terminal ends of the polymer chains. In the poly (1, 3-butylene oxide) polymer, no asymmetric carbons are present and only primary hydroxyl groups would be expected in the diol. Figure 3 clearly shows only a single sharp line for the trifluoroacetate ester.

HYDROXY- TERMINATED BUTADIENE POLYMERS

Two butadiene polymers were prepared by a living polymer synthesis. The termination of the living polymer systems was obtained with propylene oxide to give a secondary hydroxyl or with ethylene oxide to give a primary hydroxyl as the terminal group. The trifluoroacetate ester of the secondary hydroxyl polymer (Fig. 4) shows a doublet, which would hint that more than one propylene oxide unit reacted or that an asymmetric carbon was created on the butadiene end by some type of allylic rearrangement. For the primary hydroxyl terminated polymer (Fig. 5) there appears a slight splitting on the shoulder of the peak, which hints that a coupling effect from the main structural portion of the butadiene structure through the capping ethylene oxide unit appears. Work is in progress to unequivocally clarify these observations.

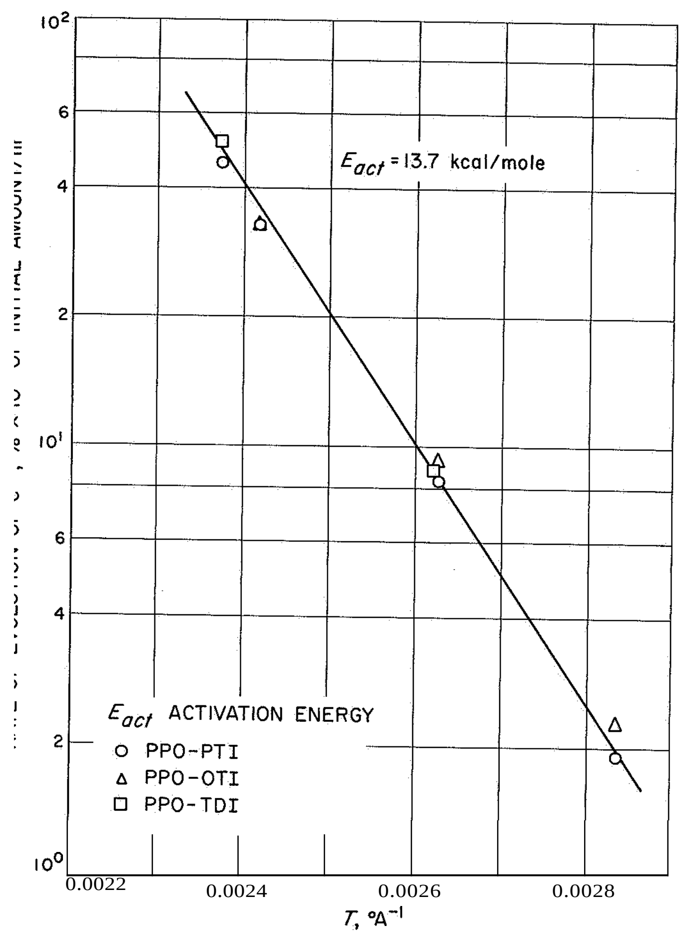


Fig. 1. Activation energy plot for C14 evolution rates for poly(propylene oxide) urethanes

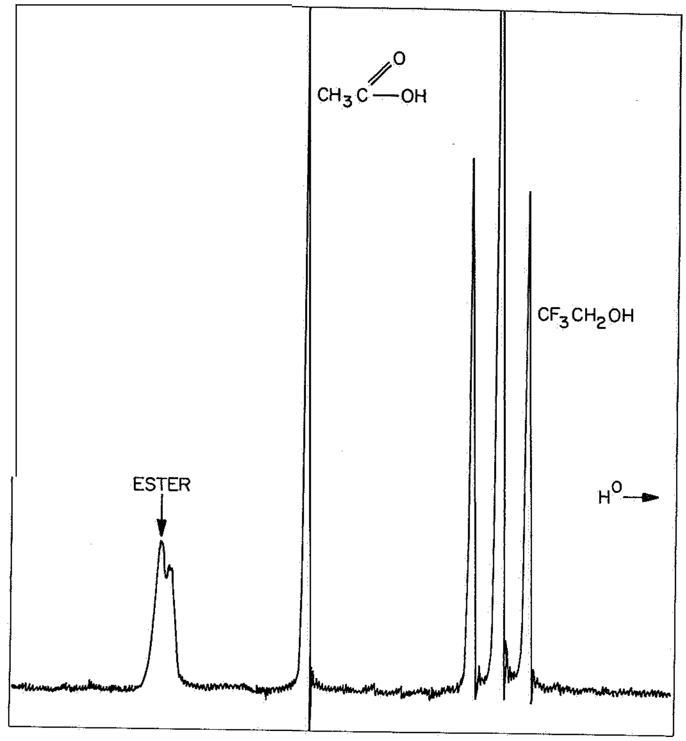


Fig. 2. F^{19} spectrum of ditrifluoroacetate ester of poly(epichlorohydrin) in benzene solution

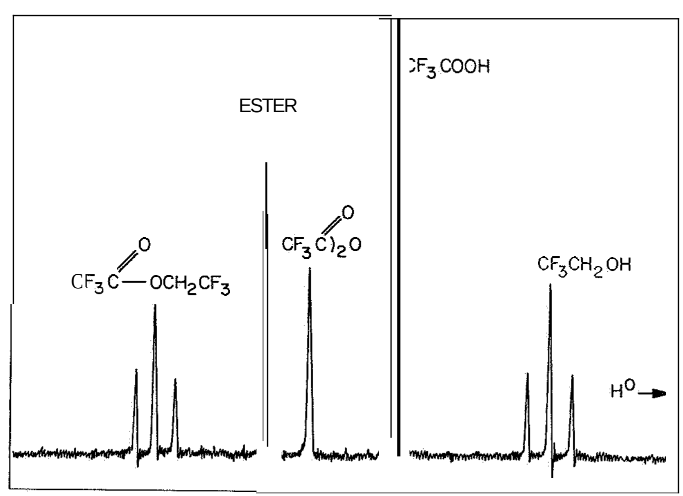


Fig. 3. F^{19} spectrum of ditrifluoroacetate ester of poly(1, 3-butylene oxide) in benzene solution

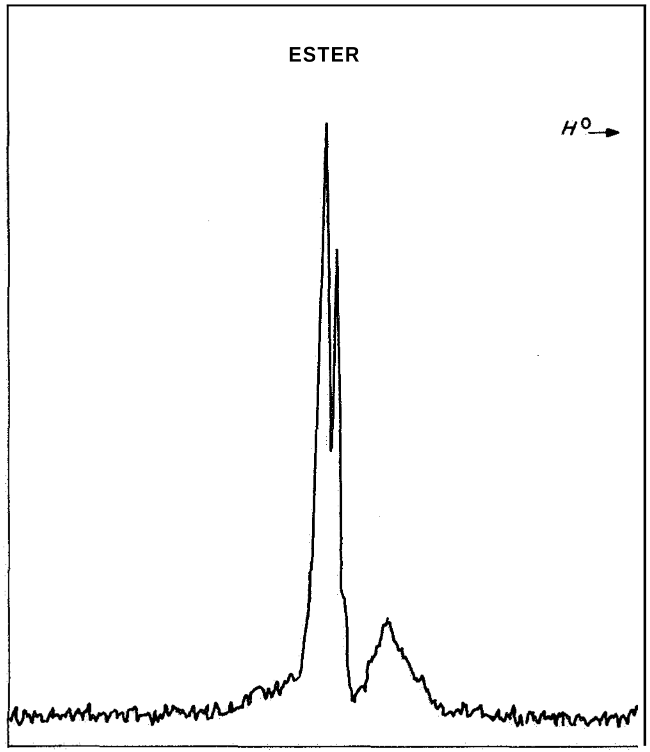


Fig. 4. F^{19} spectrum of secondary hydroxyl-terminated butadiene polymer in benzene solution

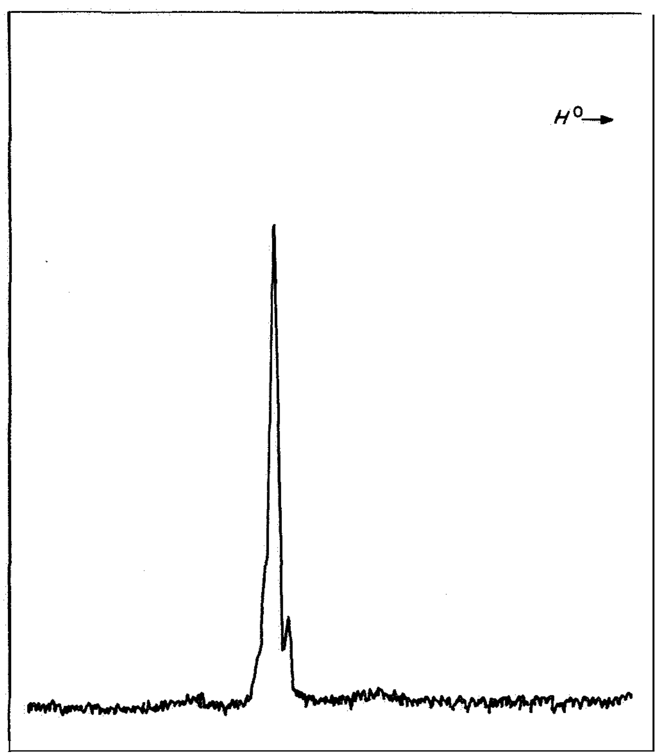


Fig. 5. F^{19} spectrum of primary hydroxy-terminated butadiene polymer in benzene solution

PROPELLANT STRESS ANALYSIS
NASA Work Unit 128-32-05-04-55
JPL 328-20501-1-3820
A. San Miguel

OBJECTIVE

The objective of this work unit is to integrate sophisticated rheological characterization studies with the best available propellant stress analysis techniques.

The propellant stress analysis program consists of a broad spectrum of activity including applied engineering, development, and pure research. This program is to review the technology of theoretical and experimental stress analysis pertinent to solid propellant, as well as to maintain JPL's leadership in these fields (Refs. 1-8).

APPLIED ENGINEERING ACTIVITIES

A current task is to evaluate the reliability of state-of-the-art theoretical treatments now being used by industry. The approach to this task is to apply the unique experimental capabilities of JPL to a flight motor, such as the Surveyor retromotor. The discrepancy between experimentation and theory (mutually exclusive) will serve as the parameter to evaluate the reliability of theoretical state-of-the-art stress analysis solutions. See Refs. 2, 6, 7, and 8.

Experimental Aspects

Four, 9-in. spherical thin-walled motor cases (for analog motor testing) have been constructed, hydrotested to 600 psi with reinforced instrumentation locating holes, and instrumented with miniature stress rosettes and thermocouples (Fig. 1). Two of these cases will be cast with JPL processed propellant and the remaining two will be cast with a three-dimensional-stress freezing epoxy. Stress and temperature as a function of time will be monitored in an experiment that will reasonably simulate the Surveyor mission. Miniature stress rosettes have been constructed and calibrated (Fig. 2) as a function of stress and temperature. The following viscoelastic mechanical properties have been obtained (e.g. , Fig. 3): (1) broad-spectrum tensile properties, (2) stress relaxation modulus, (3) creep compliance, and (4) bulk modulus. The thermal properties obtained were: (1) specific heat, (2) thermal conductivity, and (3) coefficient of thermal expansion. Other properties measured were second order transition temperature, T_g, cure shrinkage, density, and moisture absorption. These measured properties are being used to obtain a theoretical solution for the state of stress and temperature as a function of time in the 1/4-scale Surveyor retromotor.

Theoretical Aspects

A contract (NAS 7-392) has been awarded to the Douglas Aircraft's Missile and Space Systems Division to use an existing redundant force stress analysis computer program (a direct three-dimensional stress analysis) to analyze the 1/4-scale Surveyor retromotor over the same environmental regime used in the

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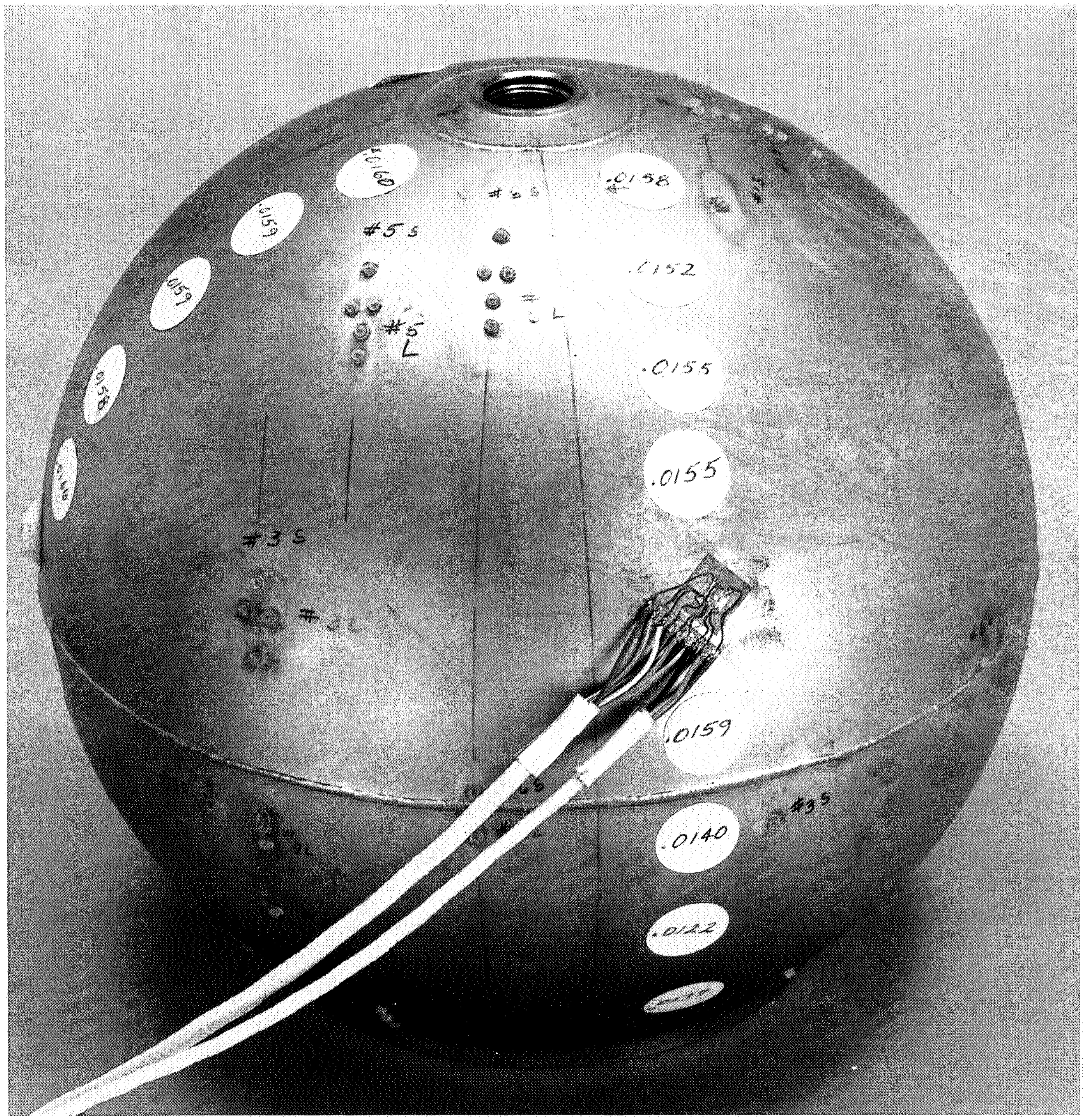

Fig. 1. 1/4-scale instrumented Surveyor retrorocket

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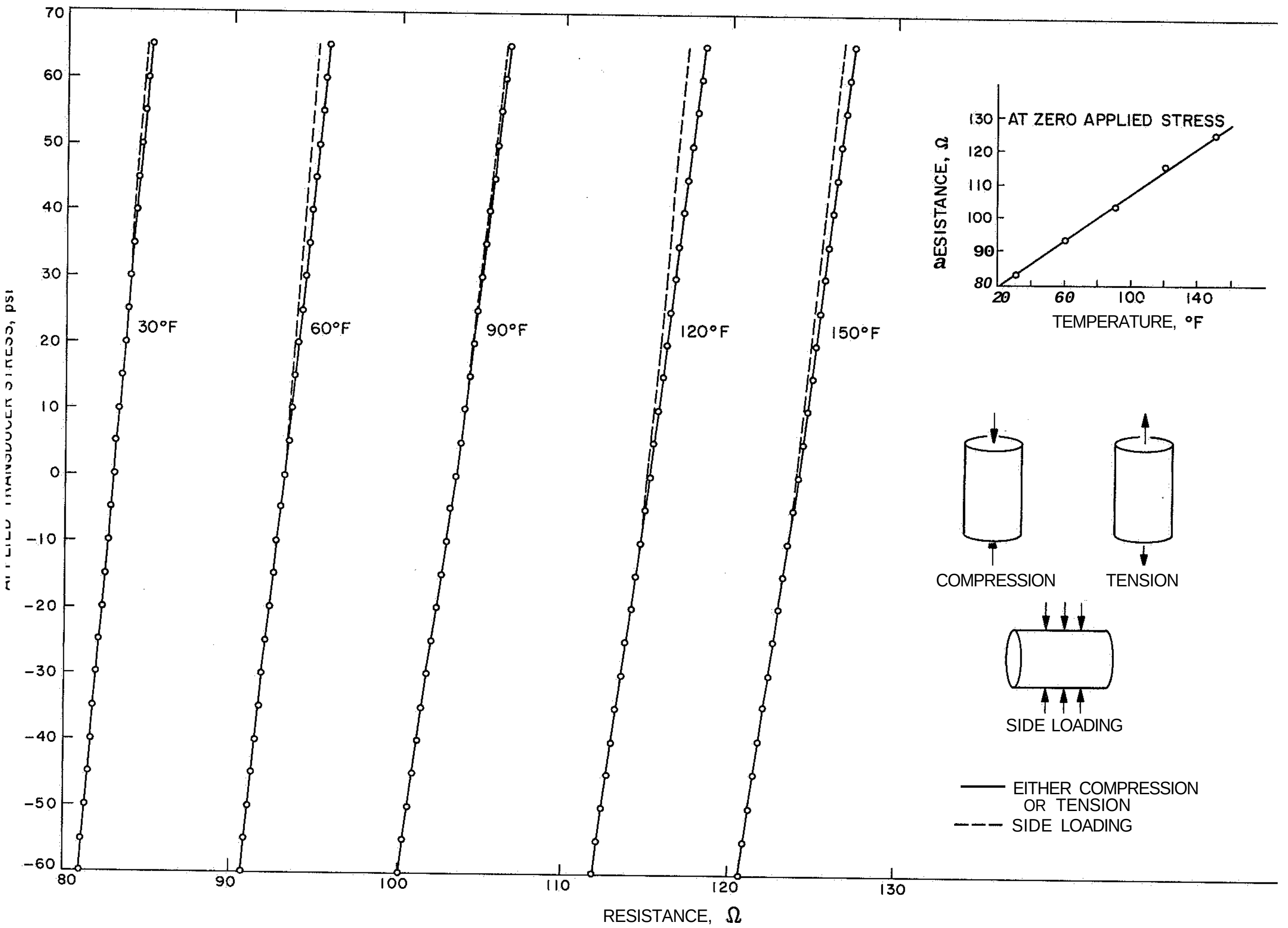

Fig. 2. Calibration of miniature stress transducers

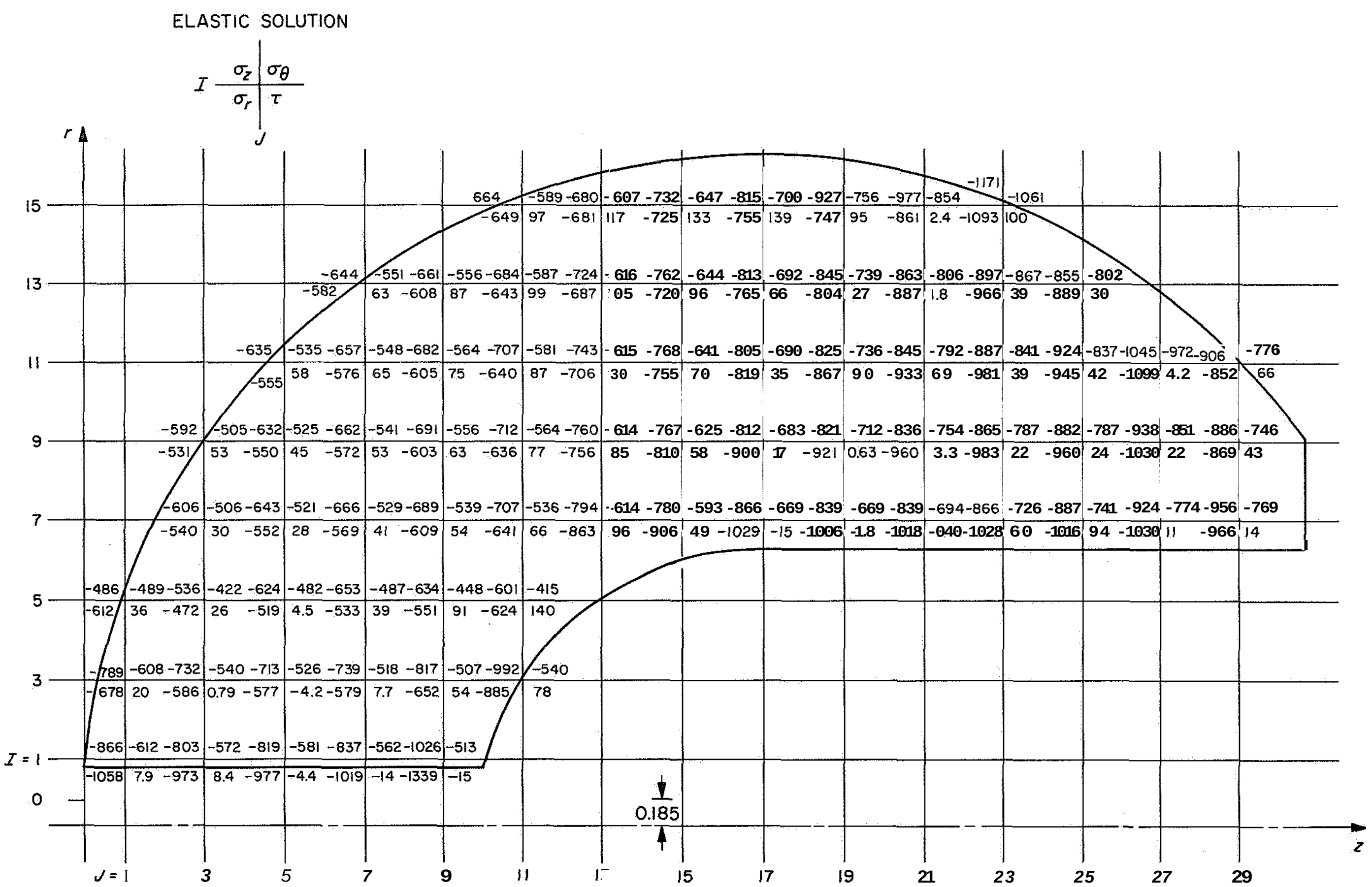

Fig. 6. Pressurization stress response of 1/4-scale Surveyor retrorocket

GAGE No.	LOCATION		
	x	y	z
1	1.474	0	4.132
2	4.360	0	-0.500
3	3.928	1.892	-0.500
4	2.314	1.114	-3.138
5	2.088	0	0

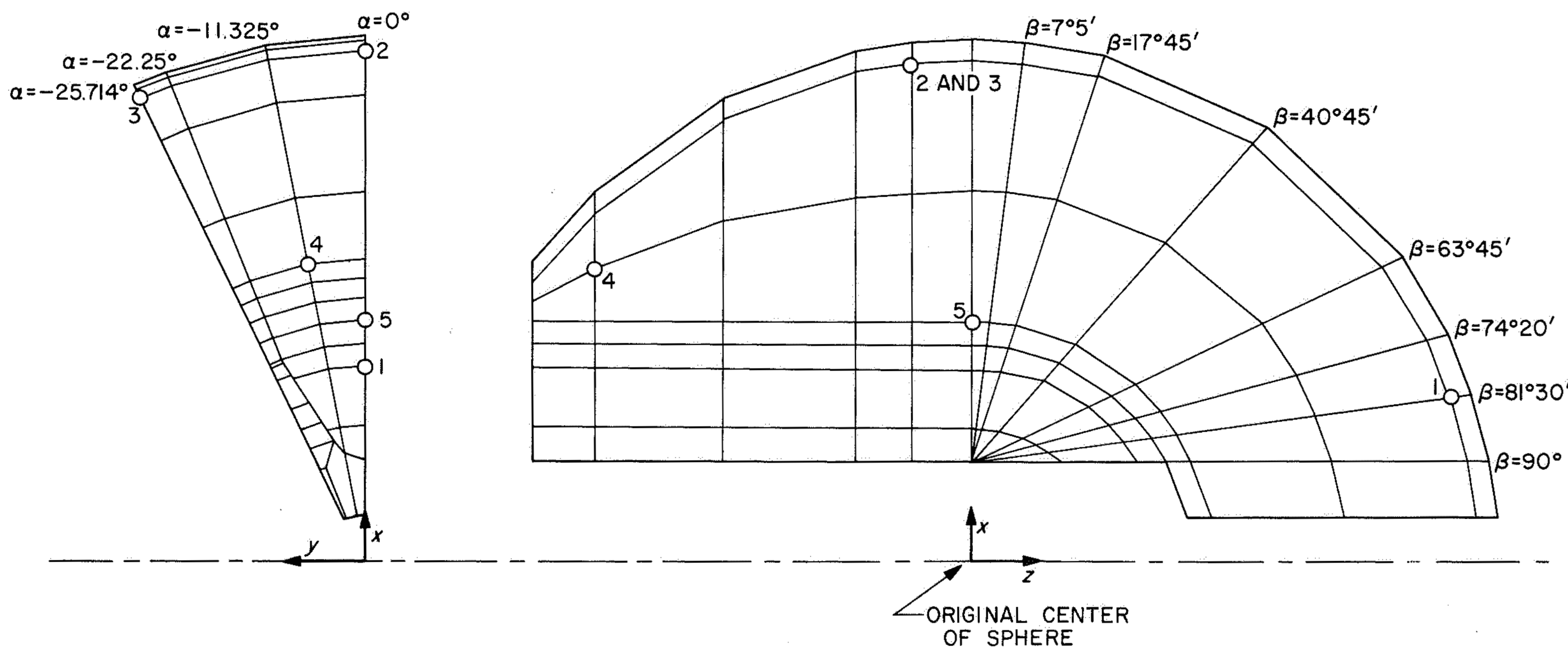

Fig. 7. Miniature stress rosette locations

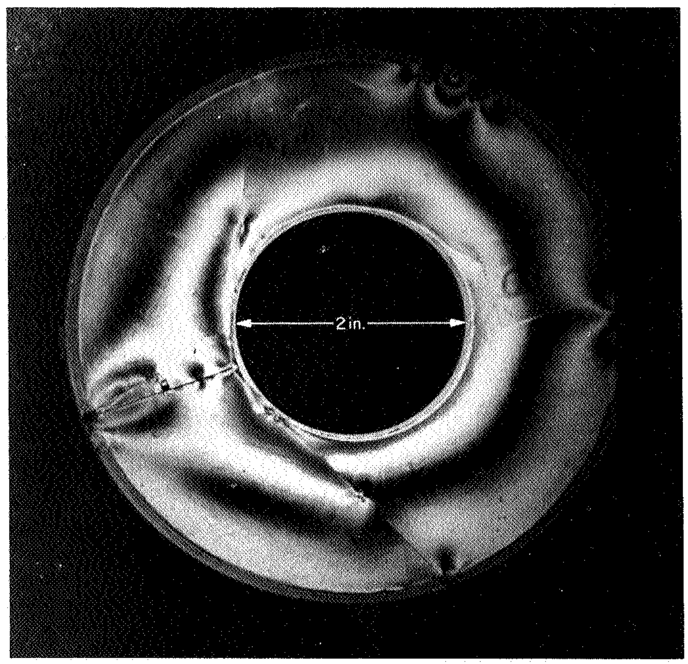

Fig. 8. Inclusion effect of thermocouple and stress transducer

MECHANICAL PROPERTIES OF PROPELLANTS

NASA Work Unit 128-32-05-06-55
JPL 328-20701-1-3820

P. A. Caruthers

OBJECTIVE

The Mechanical Properties program involves the study of the behavior of solid propellant grains in representative motor configurations under simulated operational environments.

HISTORY AND CURRENT ACTIVITIES

In the past, the effort has been concentrated on the strain test motor, the high-strain rate tester, the development of a propellant extensometer, the development of a lateral strain transducer, and torsion testing. The results of this research and development have been reported in the JPL Quarterly Summary Reports and the SPS, and in bulletins of the ICRPG Working Group on Mechanical Behavior.

Because of a lack of available manpower, the current effort is concentrated with the work on propellant stress analysis covered in detail in the NASA 128-32-05-04-55 (JPL 328-20501-1-3820) report. Most of the objectives of the test program outlined in the last 6-mo report will be realized in the motor modeling testing that is now underway in the stress analysis project.

HIGH-ENERGY OXIDIZER PROPELLANTS

NASA Work Unit 128-32-05-07-55
JPL 328-21201-2-3810

F. A. Anderson
F. J. Hendel

OBJECTIVE

The basic and general objectives of this unit are to develop high-energy solid propellant systems and to study and characterize the high-energy ingredients involved. Special emphasis is given to developing systems based on uncoated NP and HP_2.

The work covering this last 6 mo has been reported in Vol. V of JPL SPS 37-34, 37-35, and 37-36.

HP_2 CHARACTERIZATION AND PROPELLANT DEVELOPMENT

The characterization studies with HP_2 are continuing along the same lines as the work reported in the last semiannual report. A concentrated study is now being made of the effects of moisture on the HP_2. One of the most obvious effects of exposure to moisture is the change that occurs in the sensitivity to impact. The impact sensitivity of as-received HP_2 varies from 17 to 19 in. drop height for the 50% point with a 2-kg ball. By the same test, the impact sensitivity of standard ammonium perchlorate is about 33 in. Exposure of HP_2 to a relative humidity of 20% for 30 min increases the drop height of the 50% detonation point to about 25 in. A weight gain from moisture pick-up of about 1.5 to 2.0% weight gain occurs during 2 hr exposure to 20% relative humidity with a corresponding increase in the impact drop height to something greater than 48 in. (No detonations occur at 48 in. drop height.) Wet samples have been redried and the thermograms, chemical analysis, and impact sensitivity of original and redried samples compared. The analysis of samples that have been exposed to moist atmosphere and redried are essentially the same as the analysis of the original samples, This suggests a possible method of desensitizing the material for shipping. Data on the total effects of moisture are inconclusive now, however.

Two basic binder systems are being considered for the HP_2 propellant development. One is a carboxyl terminated polybutadiene polymer and the other is a relatively low oxygen content polyester. Figure 1 compares the theoretical performance potential of these two systems, specific impulse being plotted as a function of percent HP_2 in the system. For a solids loading up to 84% HP_2, the polyester system has the higher performance potential. However, if the system can be loaded to higher HP_2 content than 84%, the CTPB binder appears to offer the higher performance. Small g propellant samples are being mixed by hand in a dry box for compatibility and curing studies. Curing studies are also being conducted on the binder alone. Rather severe incompatibility problems have been encountered between the HP_2 and the binder. Efforts are continuing to understand and solve this problem, and develop a completely compatible system. Some encouraging results have been obtained.

HIGH-ENERGY SOLID PROPELLANT CONTAINING UNCOATED NP

Binder development for use with uncoated NP is going on concurrently at JPL and by Union Carbide Corporation under contract; the latter work is reported under a different heading (NASA Work Unit 128-32-05-10-55). Binder studies at JPL were divided into a new thermosetting binder and a new thermoplastic binder compatible with NP. The studies on the former binder consisted of saponification of a copolymer of ethylene and vinyl acetate and esterification of the saponified product with a large excess of succinic anhydride. The final product was a solid and, therefore, not suitable for mixing with NP.

The work on thermoplastic binder was a continuation of studies reported earlier Saturated hydrocarbons that freeze around room temperature are of special interest. Also, low viscosity is desirable to avoid high-shear mixing and resulting fire danger. Cyclohexane and cyclooctane, with or without additives, were tried as binders. Both are liquids at room temperature and solids at lower temperatures. Both these chemicals are saturated hydrocarbons and both have low viscosity at room temperature, which is most suitable for mixing with NP. Polyethylene and asphalt were investigated as additives to cyclohexane and cyclooctane. As reported earlier, polyethylene and asphalt are compatible with NP.

The work on the thermoplastic binder for NP lead to exploratory studies of a new class of solid propellants, called "cold" propellants. This term is applied to solid propellants that result from mixing of solid-liquid slurries or liquid-liquid emulsions followed by solidication by freezing at some temperature below 100°F. This term is also applied to frozen liquid monopropellants. Presently, this extreme approach is to study and possibly make use of otherwise incompatible or unstable materials.

Cold propellants containing 75% of ammonium perchlorate (simulating NP) were made using cyclohexane or cyclooctane with or without additives such as polyethylene and asphalt. Successful burning tests, so far, were made at atmospheric pressure with 1/4-lb propellants cast into an unlined glass beaker or lined motor chamber (3-in. diameter by 4 in.) with or without perforation. The burning tests were made horizontally and downward to check the behaviour of the propellant grain during firing. No dripping, or even melting, of the propellant during firing was noticed if the propellant was properly frozen. Apparently the burning rate is faster than, or at least equal to, the melting rate of the propellant. Burning rates were usually less than 0.1 in./sec. The low burning rates are especially encouraging for NP propellants that, so far, had very high burning rates. A technique for making burning rate strands is now being developed. Tubes of small diameters are made from thermoplastic rubber developed at JPL (patent pending) and filled with a slurry containing ammonium perchlorate. Such rubber makes a good liner-restrictor for this use, The conventional Crawford bomb is used for burning frozen strands.

NEW FACILITIES

An existing room is being converted into a dry-lab for remote handling of hazardous materials. This dry-lab will allow very careful control of atmospheric conditions within the room, A pair of master slave arms have been installed in this facility making possible the handling and mixing of larger propellant mixes containin the high energy materials discussed here. Figures 2 and 3 show two views of the master slave arms.

PUBLICATIONS

Hendel, F. J., "High-Energy Propellant Development" JPL SPS 37-34, Vol. V. and 37-36, Vol. V.

Hendel, F. J., "Review of Solid Propellants for Space Exploration" JPL TM 33-254, October 1, 1965.

Hendel, F. J., "Future of Solid Rockets for Space Exploration" paper presented at the 16th International Astronautical Congress, Athens, Greece, September 1965.

Anderson, F. A., "High Energy Propellant Development" JPL SPS 37-35, Vol. V.

Anderson, F. A., "Properties and Performance of JPL-533 Propellant" JPL TM 33-135.

Anderson, F. A., "Properties and Performance of JPL-534 Propellant" JPL TM 33-136.

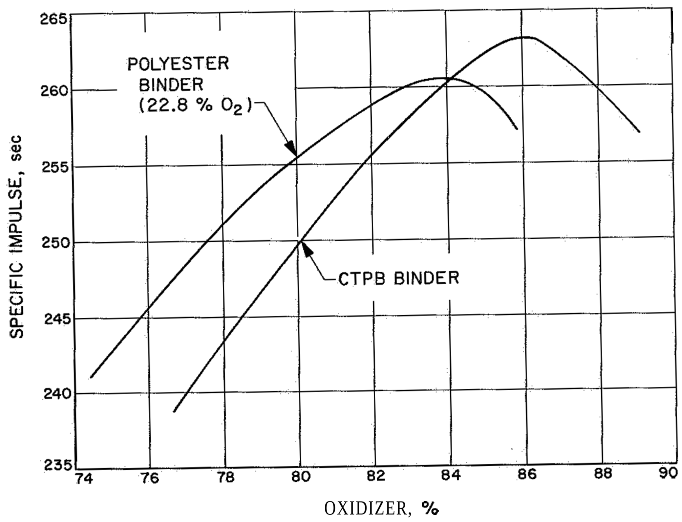

Fig. 1. Theoretical specific impulse of HP_2/binder systems

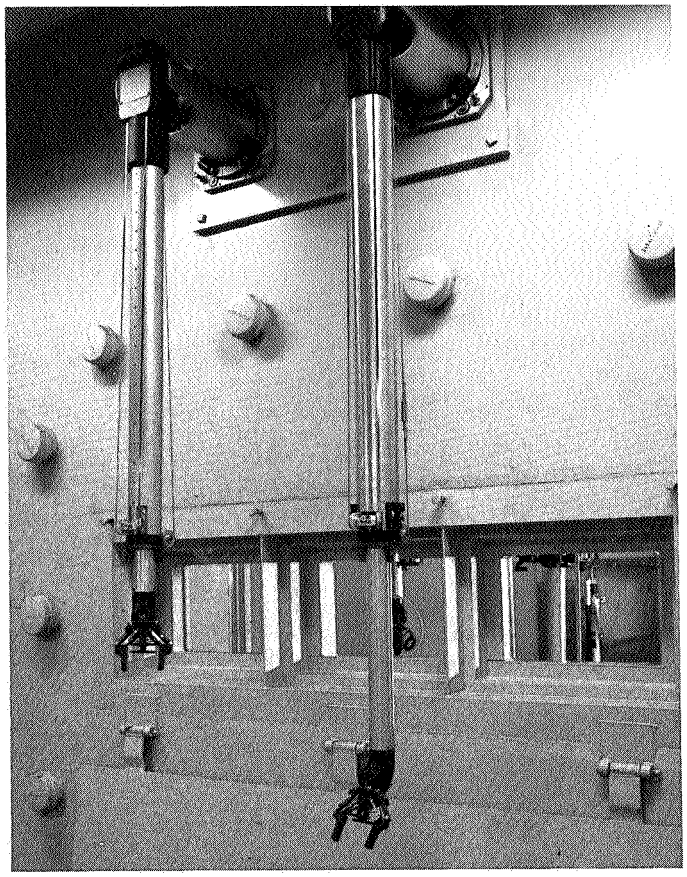

Fig. 2. Remote hazardous operations facility master slave arms

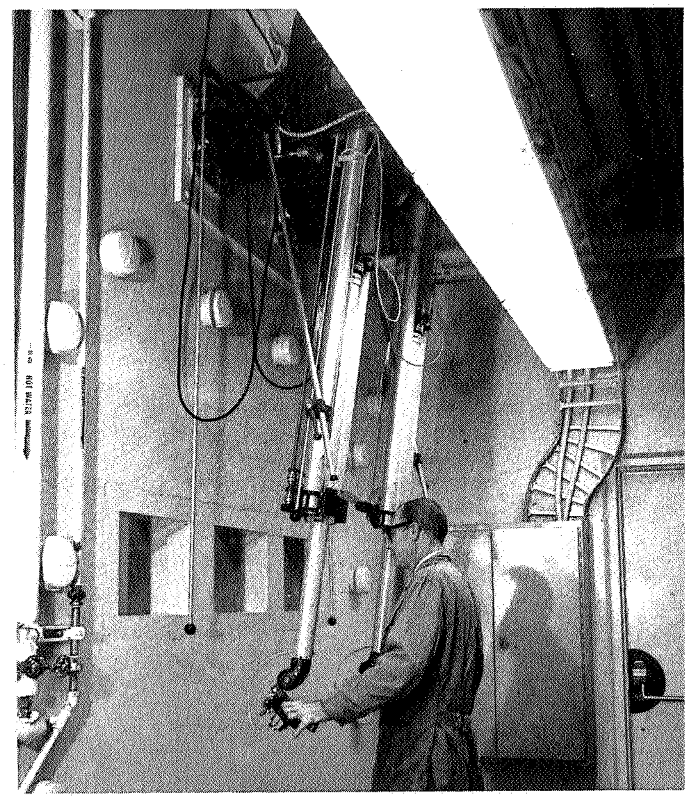

Fig. 3. Remote hazardous operations facility master slave arms in use

EVALUATION OF THE B-N-H SOLID-PROPELLANT CONCEPT

NASA Work Unit 128-32-05-08-55

JPL 328-21301-2-3810

Richard A. McKay

OBJECTIVE

This work is intended to test the B-N-H solid-propellant concept using the American Cyanamid Company system in which not all of the boron and nitrogen come from the same molecular species. The investigation includes ingredient procurement and characteristization; propellant processing review and evaluation; the design and construction of a remote-control mixer facility and a remote-control motor test stand; process development; and characterization, development, and testing of the B-N-H propellant. The immediate objective is to optimize the processing conditions to give propellant of maximum density and minimum burning rate in preparation for loading and firing motors.

PROPELLANT PROCESSING AND CHARACTERIZATION

Eleven live propellant batches were attempted as part of the process development; of these, five were successful (including the last two), one was stopped because of equipment difficulties, and three were somewhat impaired because of minor process difficulties or equipment limitations. Density specimens were obtained from eight batches, and burning rate specimens were obtained from seven. These limited data (Ref. 1) show that propellant density is strongly influenced by processing conditions, and the maximum density correlates with minimum burning rate. The propellant density is influenced during processing by bubbles formed insitu as the boron compound melts or as the ingredient hydrazine slowly decomposes, and by shrinkage as the propellant freezes instead of curing. It was demonstrated that shrinkage problems can be circumvented by using super-cooled propellant in the combustion studies but this approach is not preferred because of decomposition that occurs in the fused propellant.

The several minor problems that impaired the processing operations have been analyzed and corrected. Of these, the preparation procedure for the boron-containing ingredient and the details about the temperature-controlled vacuum casting of specimens were the most important. Also, major design changes were made in the shaft and housing seals in the mixer to eliminate corrosion, seizing, and cleaning problems.

In preparation for the proposed motor tests for ballistic evaluation, the small remote-loaded thrust stand was successfully tested for both analog and digital data acquisition using a conventional propellant.

McKay, R. A. and Udlock, D. E., "High-Energy Solid Propellant Development: B-N-H," SPS 37-35, Vol. V, p 3, Jet Propulsion Laboratory, Pasadena, California. (Confidential)

PLANNED ACTIVITIES

Very close control of pressure and temperature are required throughout processing to produce a satisfactory propellant grain. Processing studies will continue to verify the conditions that have now been established. As soon as the propellant is produced reproducibly and in enough quantity to determine the burning rate and pressure exponent over the necessary range, motor testing will start. Results with the propellant so far are encouraging.

BERYLLIUM PROPELLANT

NASA Work Unit 128-32-05-09-55
JPL 328-2 140 1-2-38 10

F. A. Anderson
H. E. Marsh

OBJECTIVE

The objective of this work unit is to develop a propellant family based on beryllium and on LMH-2 for use in spacecraft midcourse and terminal manuever motors. Facilities for handling toxic materials in-house will be provided.

LMH-2 PRODUCT IMPROVEMENT

The objective of this program was to bring about an overall product improvement in LMH-2 with special emphasis on improving the density and finding a way to produce crystalline LMH-2.

This work was done under contract No. 950894 with the Ethyl Corporation in Baton Rouge, La., and was to be completed during December 1965.

Several alternate approaches to the problem of inducing crystallinity in LMH-2 were considered and tried. The possibility of crystallizing LMH-2 from amine com-ilexes in suitable solvents was believed to offer much promise. This possibility was stuidied and explored in depth. Several different amine complexes were investigated, as well as the effects of various solvents. An intensive effort was made to find a solvent that would permit a much higher concentration of amine complex than the con-centrations that had been possible with the better known solvents. This search was unsuccessful, and crystalline LMH-2 was not produced by this technique. An attempt o effect crystallinity through ether complexing was equally unsuccessful. Other possible techniques such as chemical dissociation and digestion in weakly basic sol-rents were tried, but without success. Each time amorphous LMH-2 was produced. This work will not be continued beyond the completion of this present contract. A inal report is being prepared.

PROPELLANT PERFORMANCE EVALUATION

The objectives of this program were first to find the actual delivered perform-nce of several representative beryllium (Be) propellant systems under altitude onditions and, sec, to find the effect of chamber pressure on the delivered per-ormance.

This program was conducted in cooperation with the Rocket Propulsion Labora-ory of Edwards Air Force Base. The motor firings were made in a simulated high ltitude facility at AEDC, Tullahoma, Tennessee. The AFRPL firings consisted of our Atlantic Research Corporation motors loaded with 50 lb of Be propellant, two motors of Arcocel-333E propellant and two of Arcocel-365, and seven RPL BATES motors loaded with 70 lb of Arcocel-333E. These motors were all fired at a hamber pressure of approximately 750 psia, and nozzle expansion ratios of ominally 40:1 and 100:1. The JPL tests consisted of 20 RPL BATES motors loaded with 70 lb of propellant and used a JPL-designed nozzle. These tests consisted of oth Be-double base and Be-composite propellant as well as the respective aluminum nalog propellants fired as reference systems. All the JPL firings were conducted ith a nozzle expansion ratio of 50:1. Table 1 lists the propellant types and the espective chamber pressures of the various motor firings.

Table 1. Motor firing results

Propellant type	Chamber pressure psia maximum	No. of tests
Arcocel 319BR6 (Be)	Varied from 250 to 700	6
Arcocel 321BR (Al)	Varied from 300 to 1000	2
TP-H-1092 (Be)	Varied from 250 to 700	7
TP-H-3062 (Al)	Varied from 300 to 700	2
TP-H-3135 (Al)	650	2
TP-H-3108 (Be)	700 (submerged nozzle)	1

All the firings were successfully conducted and good performance data were obtained. The measured data show much increase in the delivered performance of the beryllium systems over that of the aluminum systems. A JPL TR on this program is being written and an abstract of a paper summarizing the results of this program has-been submitted for the ICRPG/AIAA Solid Propulsion Conference, which will be held in Washington, D.C., in July 1966.

PREPARATION FOR IN-HOUSE BERYLLIUM PROPELLANT STUDIES

Beryllium metal as a finely divided powder and beryllium compounds, such as those resulting from combustion, are thought to be extremely toxic. As a result, the Atomic Energy Commission and propulsion organizations have adopted stringent rules and practices for experimental facilities and activities dealing with such materials. For us to obtain authoritative advice on how to conduct studies of berylliumized propellants at JPL facilities with safety and with the capability of satisfying concerned local governmental agencies of such safety, the Atlantic Research Corporation, Alexandria, Virginia, was engaged, under Purchase Order No. DH5-366270 (NASA FY 1965 task No. 128-32-05-01-55) for consulting services, cost $9300.

The Atlantic Research consultants studied our facilities and practices intensively and reviewed our beryllium propellant development plans with us; they reported in oral and written form (Industrial Hygiene Consulting Services, September 1965, by Kenneth D. Johnson and Robert C. Smith). Their recommendations, in brief, are:

1. Nondetonatable (Class 2) propellants will be worked with.

2. All operations in which there is any chance of introducing beryllium materials into the air. will be totally enclosed or in hoods with adequate face velocities. Ducted blower exhausts from these operations must pass through high retentivity filters.

3. Practical upper limits for propellant studies are 2 lb mixing and 1 lb firing.

4. Berylliumized propellant operating areas must have limited and controlled access.

5. A system of personnel hygiene must be established and adhered to.

6. A system of air monitoring must be established.

Specific engineering details in their report are now being used to design facilities layout and specify needed equipment.

ADVANCED BINDER STUDIES FOR SOLID PROPELLANTS

NASA Work Unit 128-32-05-10-55
JPL 328-21501-2-3810

F. J. Hendel

OBJECTIVE

The objective of this program is to develop a new propellant binder with the special characteristics of being principally saturated aliphatic hydrocarbon, compatible with NP, and stable with AP under both heat-sterilization and space environment conditions. At the same time, the new binder should have equal or better than usual characteristics of suitability for conventional composite propellant processing and providing propellants with good mechanical properties for case bonding.

BINDER DEVELOPMENT PROGRAM

The Plastics Division of Union Carbide was chosen from five competitive bidders to develop a carboxyl-terminated prepolymer with a saturated hydrocarbon backbone. Work began October 27, 1965 at their Bound Brook, N. J. and Charleston, W. Va. laboratories under a 12-mo contract (No. 951210, FY 1965 funding, 128-32-05-01-55). The cost of the contract is $106, 878. The synthesis of the new prepolymer is based on a "buffered" polymerization reaction under high pressure between ethylene and neohexane in presence of a catalyst that at the same time, acts as the chain terminator for alpha and omega carbons. The requirement that the prepolymer have a narrow molecular weight distribution is satisfied in this synthesis because the reaction is carried out in the presence of a high concentration of chain terminator that effectively prevents the formation of a wide molecular weight distribution polymer. This one-step synthesis should offer many advantages over the multi-step synthesis in use by others.

Union Carbide will subject candidate prepolymers to screening tests to determine their functionality, viscosity, volatiles content, unsaturation (if any), molecular weight and molecular weight distribution, and compatibility with NP. Further evaluation of selected prepolymers will be made by JPL, particularly about processability, formulatability, compatibility with NP, and the properties of propellants made from them.

In their first month's work, Union Carbide made several low-molecular weight liquid prepolymers. Molecular weights were around 400. Viscosities ranged from 1200 to 2300. Functionality always appeared to be close to 2. 0. Preliminary gelling tests with a diepoxide and a tricarboxylic acid cross-linking agent appeared satisfactory.

SOLID ROCKET GAS DYNAMICS STUDIES

NASA Work Unit 128-32-06-01-55
JPL 328-21101-2-3810

R. Sehgal
L. Strand

OBJECTIVE

The long range objective is to conduct applied research in the field of ignition, combustion, and gasdynamics of solid propellant in rockets. Investigations relate to the disturbances caused by physical obstacles or unsymmetrical channels in supersonic nozzle flow, propellant ignitability after exposure to various environments, exhaust impingement phenomena and characteristics, and combustion instability.

NOZZLE THRUST MISALIGNMENT

Objective

A cold-flow experimental research program was formulated to investigate two areas of rocket nozzle aerodynamics believed to have been neglected earlier; namely, the effects (if any) of nozzle surface irregularities and throat asymmetry on the position of the nozzle thrust vector. Such irregularities and asymmetry can result from the delamination and/or erosion of nozzle ablative materials during rocket firing. This research program has attempted to answer the following basic questions: does a protrusion to the flow in the nozzle expansion region and an exaggerated asymmetry in the nozzle throat cross section displace the thrust vector and, if so, how much?

TEST FACILITY

During the report period, the checkout of the JPL Aerodynamic Facilities' newly operational three-dimensional gas-flow test facility, designated the Auxiliary Flow Channel, was finished and the complete series of tests run. A complete description of the test facility, test program, and results has been published in the JPL SPS 37-35, Vol. IV, Supporting Research and Advanced Development.

The test program was conducted using the test assembly shown in Fig. 1, the test assembly being a part of the Auxiliary Flow Channel. Thrust misalignment was found from integrated pressure data for two selected test nozzle systems. The two steel nozzles are conical and of equal throat area (1.0 in. squared) and expansion ratio (18:1). The inner surfaces of the nozzles were nickel- and chrome-plated to resist corrosion. One nozzle is axi-symmetric (Fig. 2). The nozzle has two leak-proof plugs, either of which mount in the nozzle wall 1.90 in. aft of the nozzle throat. The end of one plug lies flush with the nozzle surface, while the second plug has a 3.125-in.-square protrusion to the flow that extends 0.150 in. above the surface of the nozzle. The second test nozzle was fabricated with a known throat region asymmetry (Fig. 3). One 180-deg section of the asymmetric throat region is circular, while the opposite 180-deg section is elliptical. The area centroid at the throat is biased 0.073 in. from the nozzle center line. Both nozzles are instrumented with over 80 static pressure taps mounted in the walls of both the nozzle throat sections and expansion cones. The static pressure measurements were made with a JPL multiple pressure measuring system (MPMS), modified to withstand pressure greater than 600 psia. By numerically integrating the pressure distribution over the nozzle wall, an analytical approximation of the force unbalance normal to the nozzle axis was obtained.

TEST PROCEDURE

The tests were grouped into three series. Series A tests were run with the symmetrical nozzle and no flow distrubance, Series B with the symmetrical nozzle with the flow disturbance, and Series C with the asymmetrical nozzle. The functions of the Series A tests were both to check the flow uniformity and instrumentation accuracy of the test system and to provide a base line for interpreting the results of Series B and C. For each series, tests were run at each of seven supply pressures ranging from 100 to 600 psia. The supply temperature was only raised to a high enough level to ensure against condensation in the nozzle.

The Series A tests had to be run twice. Because of improper bonding of the chrome plating to the symmetrical nozzle surface, the plating became damaged when the protrusion for the Series B tests was installed in the nozzle. Later, all the plating was able to be peeled off, and the Series A tests were rerun.

TEST RESULTS

Experimental data reduction consisted of plotting pressure ratio profiles along different surfaces. Figure 4 shows the static wall pressure/plenum pressure ratio profiles along the protrusion center line with and without the protrusion in place. In Fig. 5, the ratioed axial pressure data for the asymmetric nozzle is shown for the two angular positions designated in Fig. 3. Asymmetric nozzle circumferential pressure ratio profiles at the axial stations designated in Fig. 3 are shown in Fig. 6. All pressure data ratioed by the plenum supply pressure was found to be essentially independent of test supply pressure.

DATA ANALYSIS

For both nozzles the net side force, summed over the nozzle axial distance, reaches a maximum and then continues to decrease as the nozzle is traversed along its axis. Figures 7 and 8 show the summed net side force profiles for the symmetric and asymmetric nozzles, respectively, along the cross sections shown in Figs. 2 and 3, The force profile maximas are caused by changing pressure ratio profiles along the nozzle axes for perturbed and asymmetric nozzles and have been analytically shown to not be solely attributable to the particular geometries of the test nozzles.

Besides the net side force calculations, asymmetric nozzle pressure data has been compared with a method of characteristics flow-field solution for a two-dimensional nozzle having the same wall profile as that of the asymmetric nozzle (Fig. 3). A combined one-dimensional isentropic, three-dimensional method of characteristics flow-analysis method was used to obtain a qualitative picture of the flow through the three-dimensional asymmetric nozzle.

Planned future activities include method of characteristics flow-field analysis of a family of two-dimensional nozzles of descending asymmetry and an investigation of the feasibility of conducting actual rocket firings to verify the cold-flow test results.

STUDY OF LOW-PRESSURE COMBUSTION AND LOW-PRESSURE EXTINCTION

Objective

The objective of this program is to conduct theoretical and experimental studies of low-pressure combustion, low-frequency combustion instability, and combustion termination.

Progress

During the report period, six low-pressure extinction tests were conducted with the United Technology Center polybutadiene-acrylic acid-acrylonitrile (PBAN) binder propellant and six tests were conducted with the Lockheed Propulsion Company nitro-plastisol propellant. Two successful tests were obtained with the PBAN propellant and three with the nitroplastisol propellant, a successful test meaning successful propellant ignition followed by regressive burning for several seconds and then low-pressure extinction. In the unsuccessful tests the propellant either could not be ignited or continued to burn after ignition until all the propellant was consumed. Although the results are inconclusive, because of not enough data, the existing data seems to show that the effect of propellant binder on low-pressure (L^*) extinction is small. This is in agreement with the results of other investigators and with existing extinction theories.

Some experimental results and conclusions drawn from this program were reported in a technical note (Ref. 1) published in the August AIAA Journal.

Activities planned for the next 6 mo include a review of all extinction data taken to date and the writing of a report summarizing the low-pressure combustion and extinction research conducted in the last 2 yr.

ARC-IMAGING FURNACE IGNITION STUDIES

Objective

The objectives of this project are to provide an adequate arc-imaging furnace facility for propellant ignition and ignitability testing and to carry out selective tests in this area.

Progress

Because of diversion of effort, progress on this project has been confined to the incorporation of a Honeywell Visicorder osillograph into the arc-imaging furnace data system. The radiation calorimeter channel has been calibrated in units of inches of deflection per millivolt input for the usable range of amplifier gain settings.

Planned activities include further instrumentation refinements and complete ignitability characterization of the heat-sterilized propellants tested earlier at one flux level and chamber pressure.

Sehgal, R. and Strand, L., "Low-Pressure Combustion of Solid Propellants," AIAA Journal, Vol. 3, No. 8, p. 1524, August 1965.

PINTLE NOZZLE THRUST VECTOR CONTROL TEST PROGRAM

Objective

The objectives of this test program are to (1) determine if a pivoted pintle-nozzle system is capable of producing side thrust large enough for nozzle thrust vector control and (2) determine the criticalness of nozzle pintle position on thrust alignment for thrust magnitude control-thrust termination pintle-nozzle systems.

Proeress

Design has been completed for a pintle system (Fig. 9) that will be incorporated into the cold gas-flow nozzle test assembly of the JPL Auxiliary Flow Channel, a test leg of the hypersonic 21-in. wind tunnel. The pintle will be capable of being pivoted about the pivot point shown. Program test variables will include the chamber supply pressure and the angular displacement (θ) of the nozzle pintle (Fig. 10). Pivot angles of 0 deg, 15 min, 30 min, 1 deg, and 1 deg 30 min will be used.

The necessary new equipment, consisting of the pintle and pivot-position system and its supporting spider, is being fabricated on lab. The Aerodynamic Facilities Section is instrumenting the existing axi-symmetric nozzle with approximately 50 more static pressure taps, giving a pressure tap net over the inner surface of the nozzle entrance section, throat section, and aft expansion cone. The tap pressures will be measured by the wind tunnel multiple pressure measuring system. From the measured nozzle wall pressure distribution and an estimate of the pressure distribution over the pintle surface, the force unbalance normal to the nozzle axis will be obtained.

Within the next report period, equipment fabrication should be finished, the complete series of tests run, and test data analysis started.

SOLID ROCKET MOTOR EXHAUST PLUME IMPINGEMENT STUDY

A statement of work titled "Study of the Effects of Impingement Upon Spacecraft From Solid Propellant Rocket Exhausts" was prepared, defining an experimental research program 6-mo long. The objective of the program, as defined by the statement of work, is to determine the design constraints imposed on a spacecraft by the impingement of gases and solid particles emanating from the rocket exhaust. All engineering data and parameters are to be defined to enable a spacecraft designer to account for the impingement effects on the spacecraft.

A Request for Proposai (No. 372560) was issued to 13 companies believed qualified to perform the program. The two responding proposals were evaluated, and Aeronutronic Division of Philco Corporation (ADP) was selected. Negotiations between JPL and ADP were started, and preliminary agreement was reached on the terms for a Cost Plus Fixed Fee contract. Total contract cost will be $73,325. The contract, in final form, is now being prepared by JPL Procurement.

The contract will be started early in the next report period and will extend slightly over its duration.

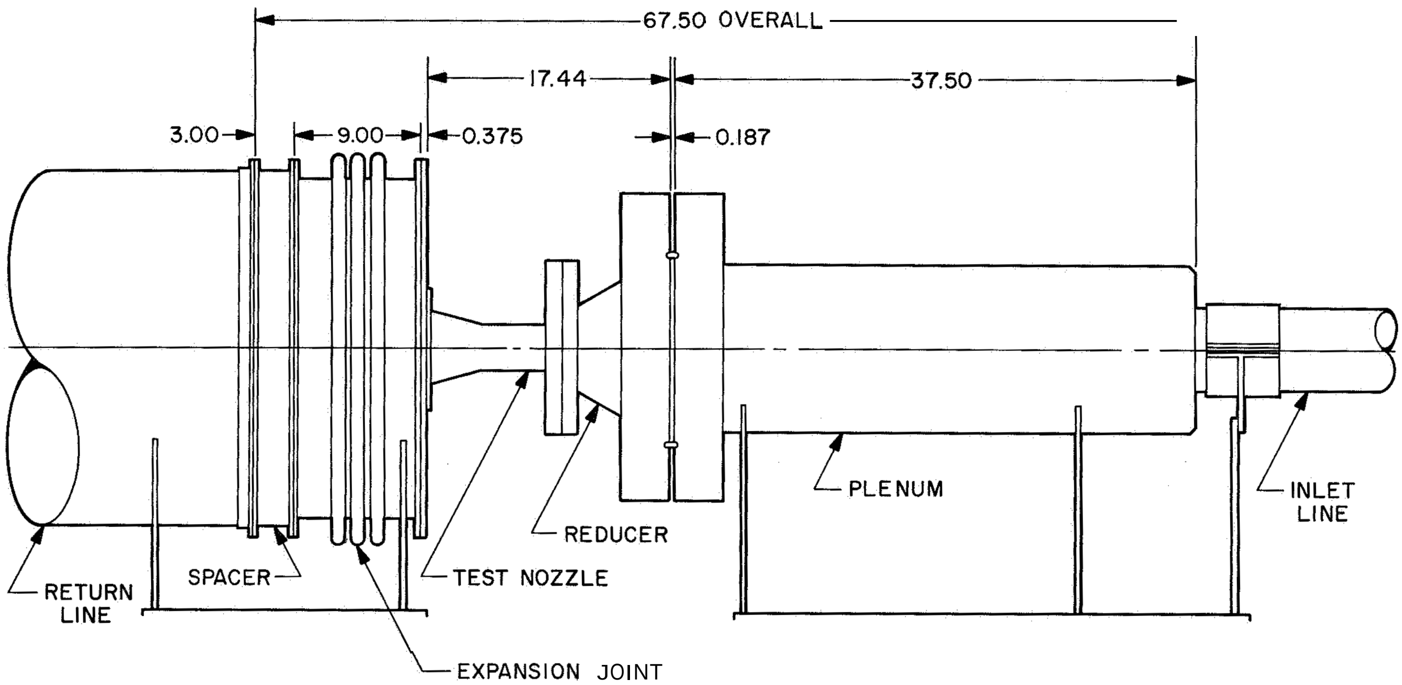

Fig. 1. Gas-flow nozzle test assembly

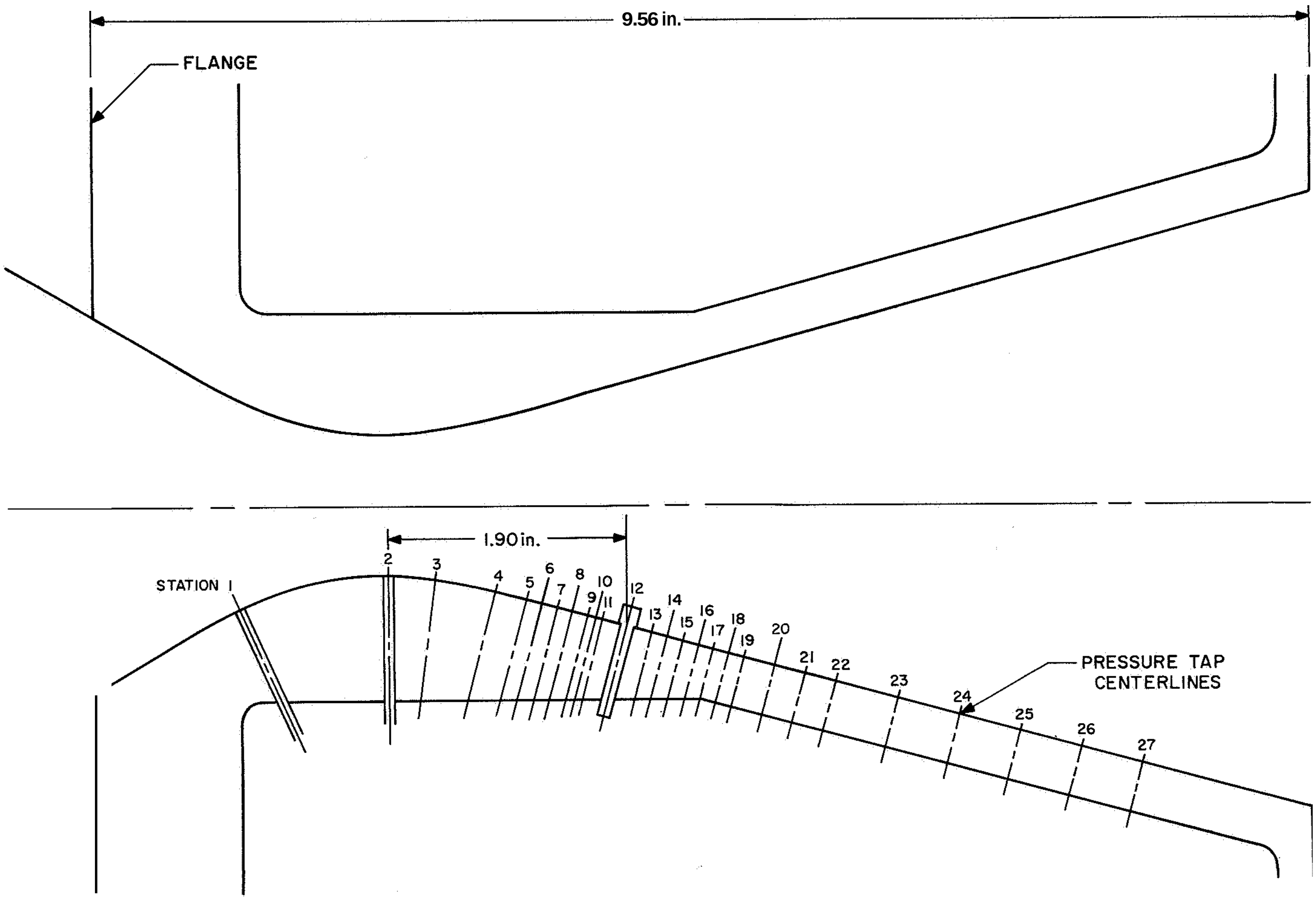

Fig. 2. Symmetric nozzle cross section

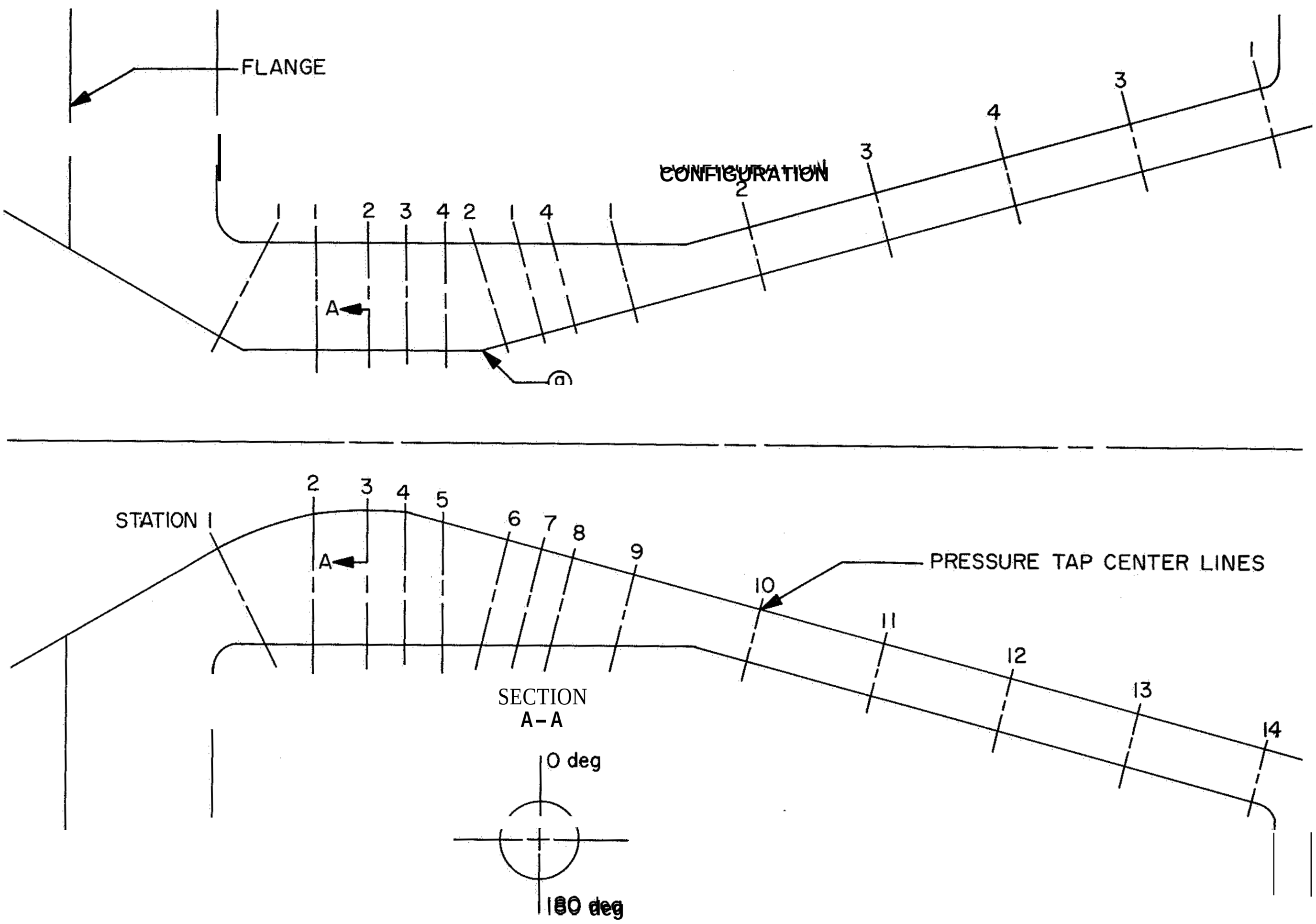

Fig. 3. Asymmetric nozzle cross section

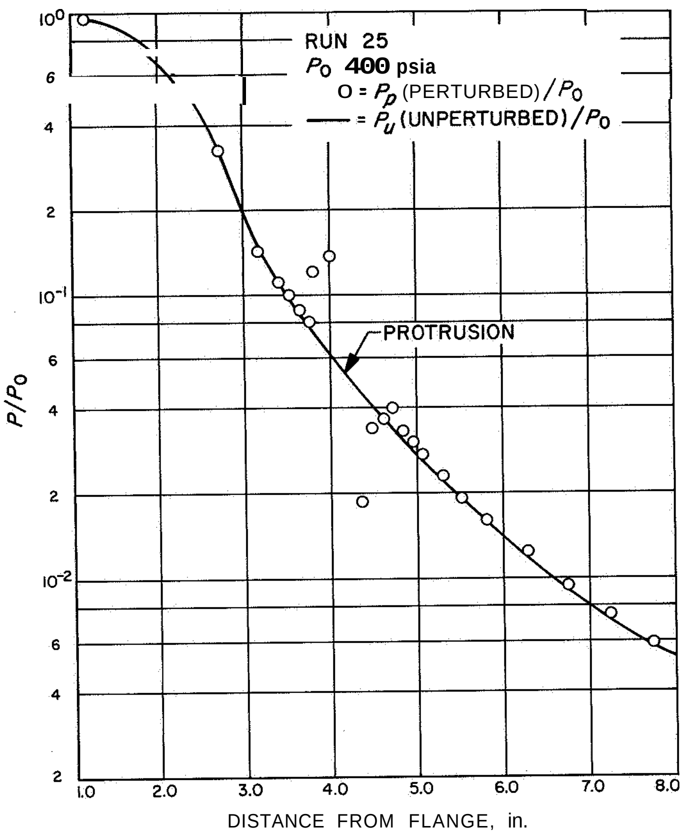

Fig. 4. Perturbed and unperturbed wall static pressure ratios vs nozzle axial distance, symmetric nozzle

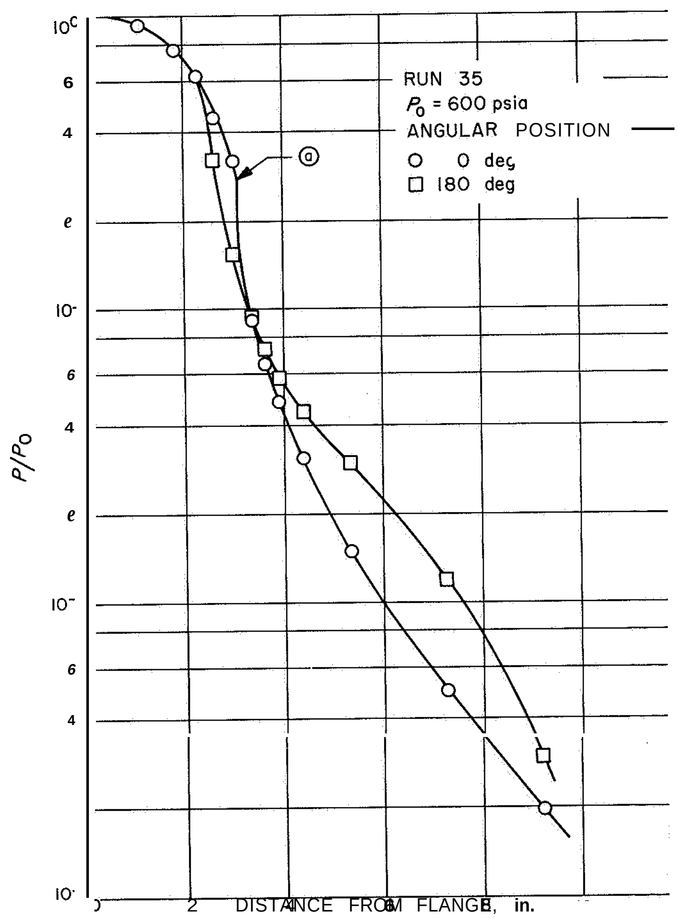

Fig. 5. Wall static pressure ratio vs nozzle axial distance, asymmetric nozzle

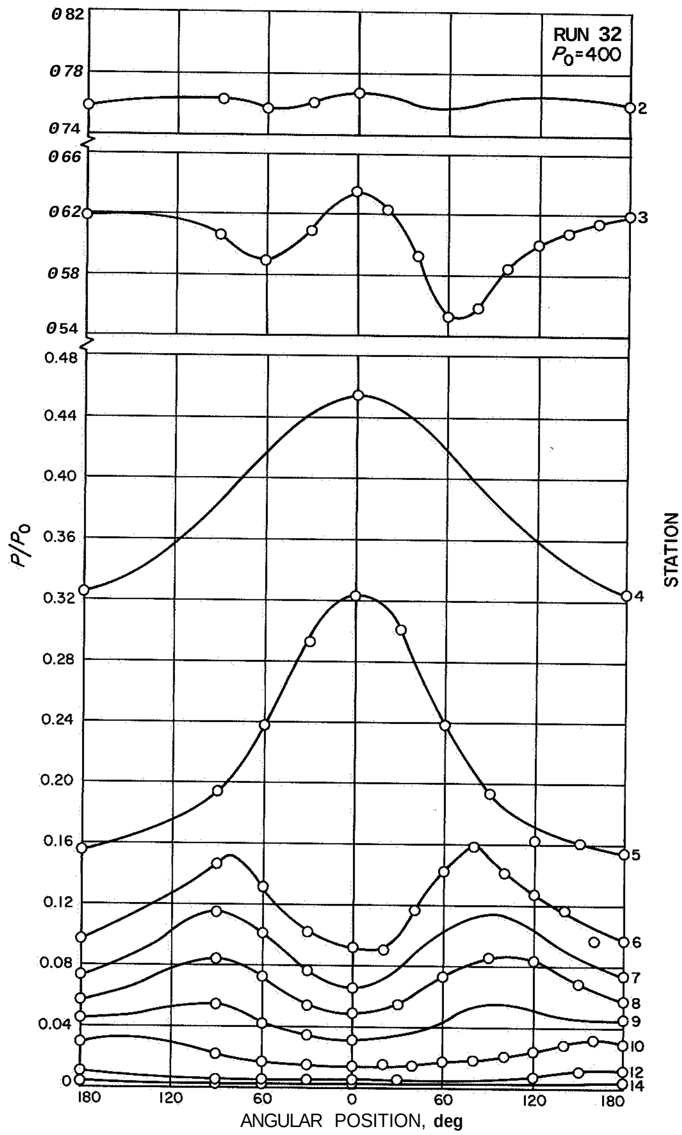

Fig. 6. Wall static pressure ratio vs nozzle angular position, Asymmetric nozzle

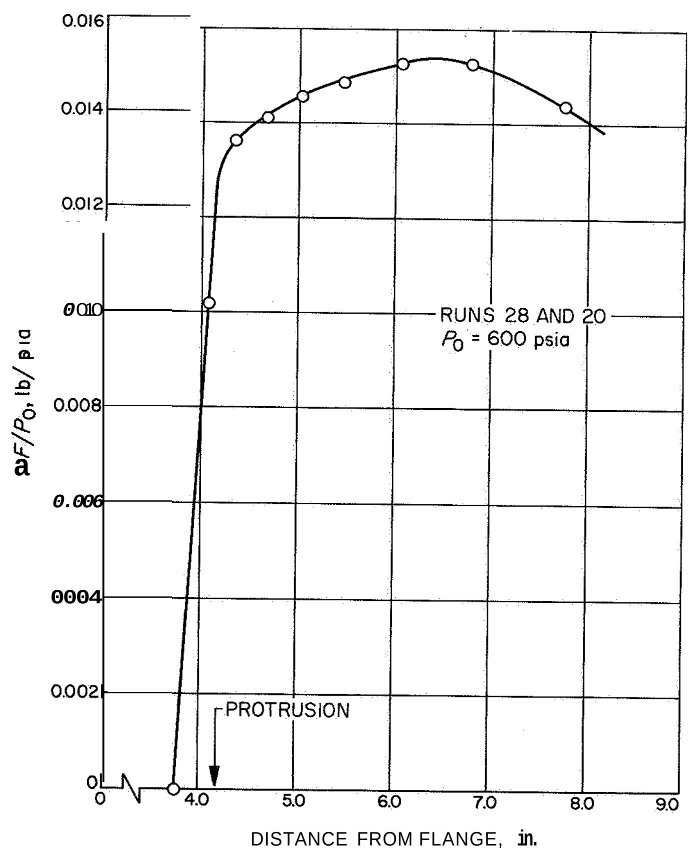

Fig. 7. Summed net side force/supply pressure ratio vs nozzle axial distance, symmetric nozzle

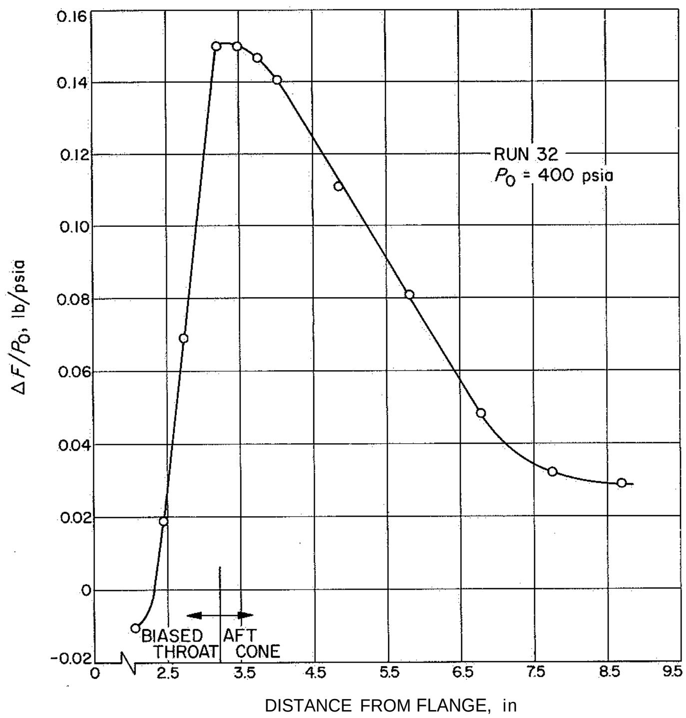

Fig. 8. Summed net side force/supply pressure ratio vs nozzle axial distance, asymmetric nozzle

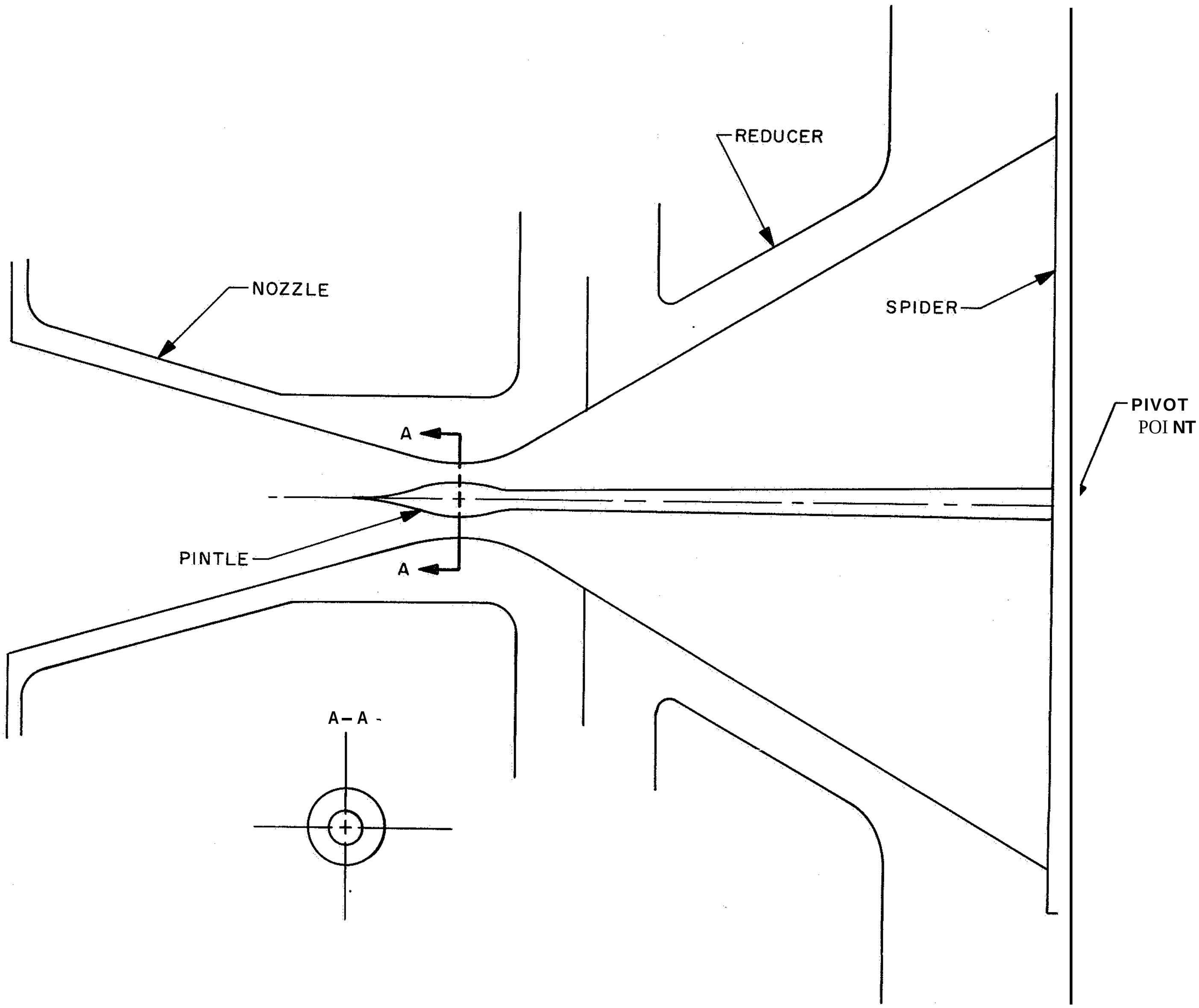

Fig. 9. Pintle-nozzle system

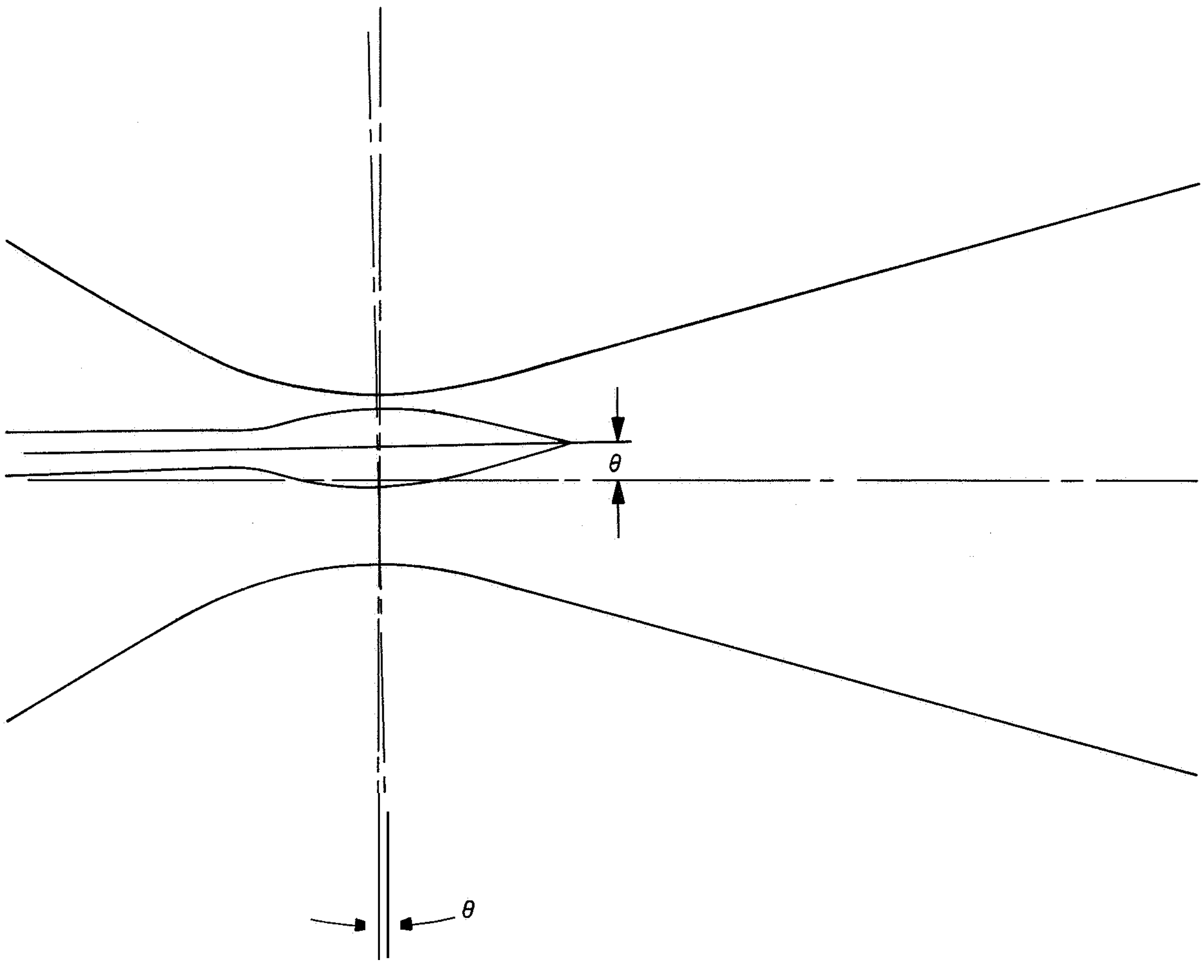

Fig. 10. Pintle angular displacement

CHEMICAL ROCKET EXPERIMENTAL ENGINEERING (731)

LIQUID SPACE PROPULSION SYSTEMS (731-12)
ALPS PROJECT

NASA Work Unit 731-12-03-01-55
JPL 331-10101-2-3840

R. N. Porter
H. B. Stanford

OBJECTIVE

The objective of the ALPS project is the development of an advanced propulsion system, simplified (compared to present systems), dependable, capable of high performance, and versatile for use as a retro-rocket, midcourse propulsion unit, or return launch rocket.

ALPS DEVELOPMENT

The problem of preventing the explosive decomposition of residual hydrazine trapped in the ALPS gas generator injector after shutdown was the subject of a short design study. Last year's pressurization subsystem tests demonstrated one solution: immersing the injector housing in the main fuel line *so* the heat soaking into the injector from the hot catalyst bed and generator shell is carried into the fuel, The current study was aimed at finding whether the generant tank could serve as a suitable heat sink. Analytical results showed that a combination of high thermal resistance between the generator shell and injector housing, plus a high conductivity path from the injector housing to the generant tank should work well. The former reduces the rate of heat flow from the shell and bed to the housing while the latter conducts the heat into the tank fast enough to avoid high temperatures in the housing. Drawings were made of the modified injector housing, the high resistance "head" end part of the generator, and special plate to simulate the heat sink characteristics of the generant tank. Hardware fabrication and testing during the second half of FY 1966 will be dependent on the availability of manpower.

A brief report on the first three ALPS pressurization subsystem tests appeared in JPL SPS 37-35, Volume IV, October 31, 1965. Termination of contract personnel at the end of FY 1965 and the reassignment of some JPL personnel resulted in reduced ALPS testing. Pressurization subsystem tests, started in FY 1965, could not have gone on anyway, because the redesign and fabrication of the heat exchangers was not complete by the end of the reporting period. These tests will go on during the next reporting period.

The transient analysis proposed in the FY 1965 second half progress report is not planned to be started, because of no manpower.

A short resume of the ALPS program was published as one section of JPL TR 32-735, On the Evolution of Advanced Propulsion Systems for Spacecraft by Dipprey, et al., July 15, 1965.

ALPS EXPULSION DEVICE DEVELOPMENT

Several composite bladder materials made up of Teflon film, aluminum foil, and Teflon felt (in varying arrangements) have evolved from the Dilectrix Corporation contract ($44,000) for JPL. These materials have been tested for permeation and endurance, and selections made from which actual expulsion bladders will be fabricated over the next 4 mo as a part of this same contract.

The Arde Inc. contract ($20,000) has resulted in the fabrication and testing of an 18-in. wire reinforced stainless steel hemisphere expulsion device (three more are to be completed) shown in Fig. 1. In test, this diaphragm achieved three complete reversals before a leak developed and a fourth reversal before some reinforcing wires loosened. It is planned to supplement this contract with $25,000 for developing an integrated lightweight tank and diaphragm assembly in 18-in.-diameter size. This work should be done during the third and fourth quarters of FY 1966.

The contract with Honeywell for fabricating convoluted diaphragms from stainless steel and titanium and to develop recycling capability in aluminum convoluted diaphragm has been dormant for the past few months. The reasons are twofold. First, it was difficult to find a vendor to supply the thin-walled stainless steel and titanium hemisphere from which the convoluted diaphragms would be formed. Second, it was necessary to change the "scope of work" to allow more effort to be applied to the buckling problem of the outer convolution of the aluminum convoluted diaphragms. Negotiations to supplement the existing contract with $15,000 are now reaching the final state. It is planned that much of this effort will be completed during the last half of FY 1966.

A contract for $50,000 to establish chemistry services for the expulsion devices development program is now being negotiated. Specifically, this contract is to provide development effort for:

1. A long term permeation test device and readout for N_2O_4,
2. Studying basic Teflon structure for inhibiting permeation.
3. Plating metal onto Teflon to create an impermeable and flexible bladder material.

The contract will also provide for day-by-day permeation and compatibility testing on such bladder material samples as are made available.

Several reports dealing with expulsion devices both metallic and polymeric are either in publication or are being written now. The documents should become available during the third or fourth quarter of FY 1966.

MATERIAL COMPATIBILITY TESTING

Specifications outlining every necessary step in procuring, preparing, testing, and analyzing results of the new JPL materials/propellants compatibility test method were completed; these specifications mainly apply to testing with fuels and a slightly modified procedure will have to be written for testing in oxidizer.

The design of the building for housing approximately 2000 fuel and oxidizer samples was completed but there have been some delays in obtaining all of the required approvals for construction to start. Nevertheless, the building is expected to be completed by the end of the third quarter of FY 1966. All of the glassware to make the individual sealed capsules has been received except for the stressed sample holding fixtures; the holding fixture design proved to be inadequate *so* a redesign was necessary. A list of materials to be tested was generated. Procurement action was being started at the end of the first half to secure the materials samples, to prepare them for test, and to seal them with propellant in the glass capsules, Current schedules call for essentially all samples to be in test by the end of FY 1966.

Two reports covering the development of the test method are expected to be published in the third quarter of FY 1966.

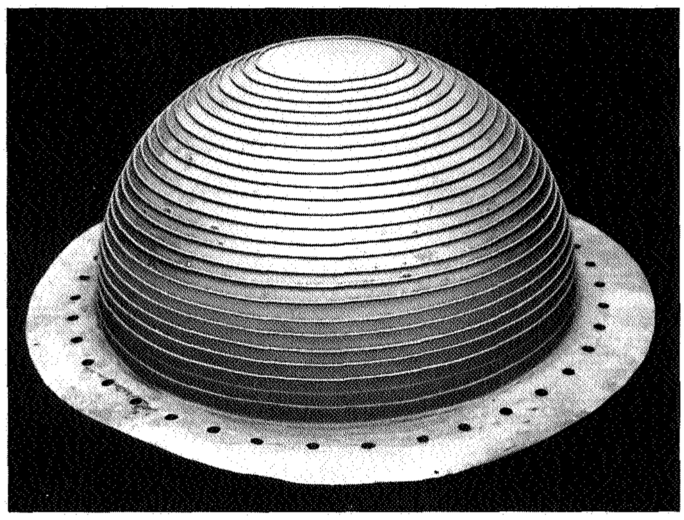

Fig. 1. 18-in.-diameter stainless steel, wire-reinforced expulsion diaphragm

ALPS COMBUSTION DEVICES

NASA Work Unit 731-12-03-02-55
JPL 331-10301-2-3840

D. D. Evans

OBJECTIVE

The primary goal of this work unit is the development of a liquid rocket engine for the ALPS. The secondary goal is the advancement of the state of the art of liquid rocket injectors, including valves, and thrust chambers. The current fiscal year objectives are to complete the feasibility demonstrations of each major subcomponent: the propellant valve, the injector, and the thrust chamber.

PROPELLANT VALVE

Design has been completed on a throttleable propellant valve that is to be integral with the 2000-lb thrust (2K), 78-element, unlike-impinging-sheet injector described in the next section. Figure 1 is a cutaway sketch of the valve.

The valve will perform two basic functions. First, it will provide positive propellant shutoff in vacuo (without the cold-welding of metal surfaces) by a unique tapered plug constructed of alternating laminations of Teflon and metallic disks. Second, it will throttle propellant flow rate over a nominal 20:1 range at constant injection pressure of 225 psi by progressively closing off individual injector orifices.

The functioning of this valve concept may be described briefly as follows. Motion of the stem toward the bottom of Fig. 1 first unseats the tapered plug and permits the propellant to travel as far into the valve as the second laminated plug. Further downward motion of the stem causes this second plug to progressively uncover holes passing through the wall of the valve body and arranged in a descending spiral pattern around its periphery. Each of these holes is connected to an individual injector orifice by a long, smooth tube to ensure that the hydraulics of each orifice will be predictable and identical. Appropriate arrangement of this external tubing will permit a wide variety of orifice shutoff sequences.

The liquid volumes within the valve have been minimized, and the length of stroke was selected for maximum throttling sensitivity consistent with good control. Besides providing a dynamic seal, each of the two bellows also serves to balance pressures within the valve, so that low actuator power is required. No auxiliary springs are necessary. Minimum "pumping" of liquid between the internal cavities is expected.

Design of this component is complete except for detail drawings. Fabrication and flow-testing of a prototype unit will be done during the next report period.

INJECTOR

A major activity of the ALPS Injector Program has been the investigation of reaction effects on the combustion process. The extremely rapid reaction rate of the hydrazine-nitrogen tetroxide propellants can result in the disruption of the mixing process, resulting in low efficiencies with some impinging-doublet injector designs. During this time, additional stream separation experiments were completed at the

10-lb thrust per element scale. These results were described in JPL SPS 37-36, Vol. IV. The experimental aparatus used is shown in Fig. 2. Figure 3 shows the data for all three sizes of impinging-doublet elements that have now been tested. The relative shape of each curve shown in Fig. 3 shows that the larger 0.236-in.-diameter streams are severely disrupted by the rapid reactions at the impingement interface, but the 0.020-in.-diameter streams penetrated and mixed well, as evidenced by the occurrence of an optimum performance value for the instance without side spray flow. The exact size at which the disruption process starts to dominate the propellant mixing occurs at some size between the 0.020-in. and the 0,064-in.-diameters. These experiments conclude the investigations on the reaction effects phenomenon with hypergolic propellants. The original 2000-lb-thrust test results were formally published in JPL TR 32-689, An Experimental Investigation of Combustion Effects on the Mixing of Highly Reactive Liquid Propellants, by Bruce H. Johnson. This report also describes attempts to mechanically induce propellant mixing, and a complementary investigation on the effects of reaction inhibitors on the mixing process. A formal JPL TR describing all these results at the 2000-, 100-, and 10-lb-thrust levels is now in preparation

After consideration of several alternative injection schemes, it appeared that the concept of thin-sheet impingement was an advantageous method of carrying out good mixing of these highly reactive propellants. An impinging-sheet-doublet element was chosen to take full advantage of the existing knowledge concerning unlike doublets. Each sheet of the element is formed by directing a jet against a suitable solid reflector, as shown in Fig. 4. Individual 25-lb-thrust elements of this design have reached reproducible high performance with N_2O_4-N_2H_4 propellants in an uncooled thrust chamber, An extensive parameter optimization program has been completed: results of which are reported in SPS 37-34, Vol. IV, Page 174, and SPS 37-35, Vol. IV, Page 152. The results of this optimization program show that:

1. Sheet impingement angles of 90 to 120 deg are acceptable.

2. Close deflector spacings, on the order of 0.050 in., are desirable.

3. Developed sheet lengths on the order of 0.25 in. are best.

4. Orifice fluid velocity does not appear to have a strong effect on performance; velocities of 90 to 100 ft/sec produce smoother combustion.

Data from this investigation was used to design multielement 100- and 2000-lb thrust injectors. During this report period, the final brazement of the 100-lb thrust impinging-sheet injector was completed. This injector is designed to operate with film-cooling only, and is constructed of molybdenum (a highly conductive refractory metal). An integral valve was also designed and fabricated. This valve features direct, smoothly-transitioned flow into each injector orifice, with sealing directly upstream of the orifices to obtain minimum manifold volume. Unfortunately, because of the extremely close tolerances required for a valve of this size, difficulty has been encountered in the brazement process. Modified designs are now in process that should solve these problems. Assembly of this valve will be completed, and first test firings conducted with this injector/valve combination during the next 6 mo.

The 2000-lb thrust impinging sheet injector is now in fabrication, and it is anticipated that assembly will be completed, and test firings conducted during the next report period. Limited throttling tests will also be done during this test program. Results of these tests will be used in the design or redesign of the throttling valve described earlier.

Results of an earlier study on the basic N_2O_4-N_2H_4 reaction, conducted by a contractor (Dynamic Science Corporation) led to the discovery of detonable intermediate products that are formed by these propellants if they have been mixed and allowed to react slowly while very cold. Because these results are believed to be applicable to the ignition "spike" problem, now being investigated at several agencies, it is planned to continue studying the basic reaction during this fiscal year. Procurement action is now underway through NASA WOO to let a contract for this.

THRUST CHAMBER DEVELOPMENT

The ALPS Thrust Chamber Task has concentrated mainly on pyrolytic graphite alloys for chamber construction. During this period, a water-cooled 2000-lb thrust injector, designed for long duration testing with free-standing pyrolytic graphite thrust chambers, was test fired in a series of short duration heat-flux tests. Also, an attempt was made to conduct a long-duration test in a water-cooled thrust chamber. However, this test was stopped after a few seconds when the water-cooled thrust chamber burned out in the throat area. Because the burnout did not appear to be related to the injector, but rather to a faulty chamber design, the injector was committed to a long-duration firing with a pyrolytic graphite thrust chamber. During the checkout phase before the actual firing, the pyrolytic thrust chamber was fractured by loads induced by the cooled mounting flange. This is the first occurrence of this type during this program and the specific reason is not yet known. A detailed analysis will be conducted to find the cause, and another long-duration firing attempt will be made after necessary design changes are completed.

A 100-lb thrust pyrolytic graphite test program is in progress in parallel with the 2000-lb work. Firings of 100-lb pyrolytic graphite units were not conducted during this period, because the injector and thruststand facilities normally used for this program were committed to support the Refractory Metal Coatings Evaluation Task (128-31-06-06-55), which was conducted in support of Contract NAS 7-113, with IIT Research Institute, A chamber/injector adapter was designed and fabricated; however, tests will be conducted with this adapter during the next period to provide film-cooling along the boundary of the pyrolytic graphite chambers,

A contractor (Solar Aircraft Co.) has been conducting a research program under the sponsorship of this task to develop techniques and materials for brazing pyrolytic graphite to refractory metals. This program has been successful in developing high-strength brazed joints, and it is planned to braze a free-standing pyrolytic graphite thrust chamber to an injector during the next period.

The design of a thrust chamber and associated apparatus to provide the ability to withdraw gas samples from the boundary during a firing has been completed, and fabrication of the component parts of this apparatus has also been completed (except for a small filter element). During the next report period, it is planned to award a contract for the actual testing and the analysis of the extracted gas samples. This 100-lb thrust work supplements the earlier work with this injector type, so that a full characterization of this injector will be obtained.

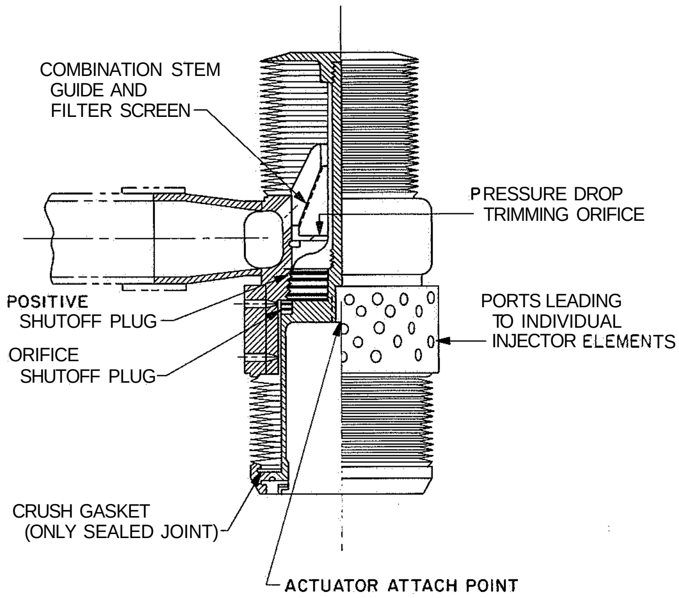

Fig. 1. Propellant valve design

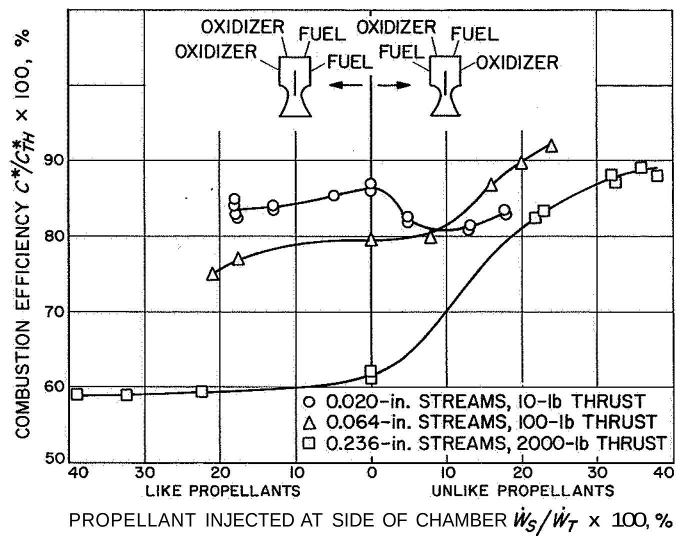

Fig. 3. Combustion effects test results for three sizes of doublet elements

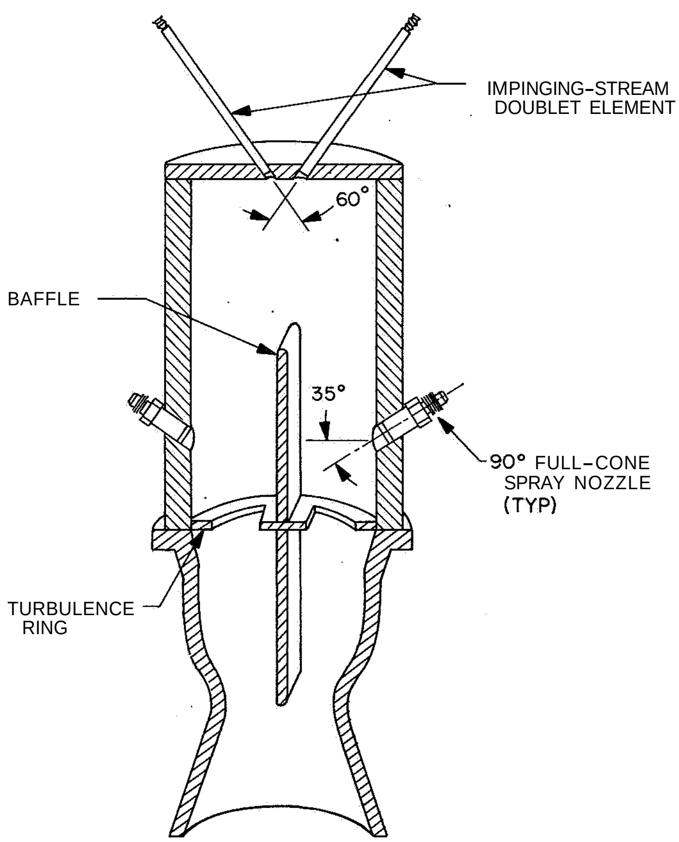

Fig. 2. Experimental apparatus for evaluating combustion effects in sprays

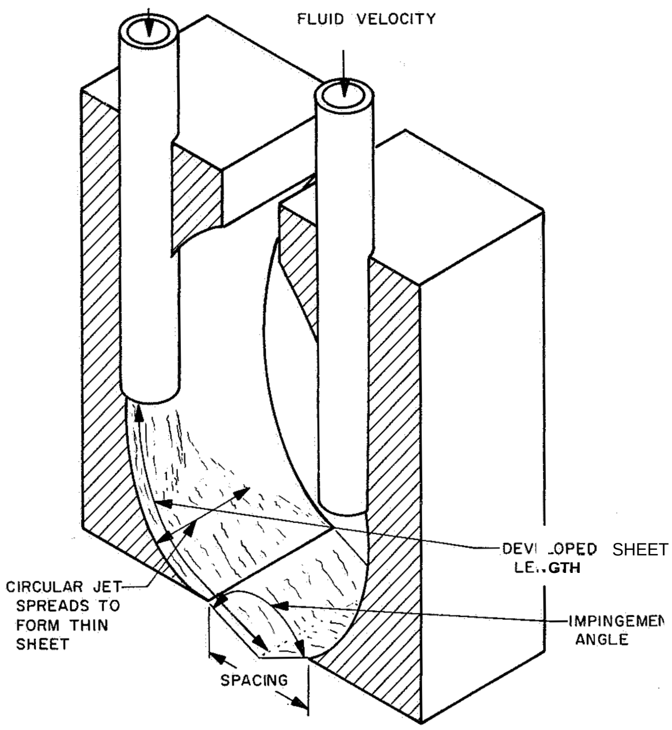

Fig. 4. Key parameters involved in imping-sheet doublet element optimization

ADVANCED LIQUID PROPULSION COMPONENTS

NASA Work Unit 731-12-03-03-55
JPL 331-10201-2-3840

L. R. Toth

OBJECTIVE

This work unit has as its objective the development of specific components needed in a space exploration vehicle using the ALPS concept. Each component design formulated is intended to be an advancement in the state of the art. This new generation of devices will satisfy the requirements for flow controls such as valves (and their control mechanisms) that are extremely reliable and have accurately repeatable performance while operating during the mission and in the space environment for periods up to 2 yr.

Much work has been done on the following components: the generant tank and cell assembly, generant controller, pneumatic and liquid fill valves, and heat exchangers.

GENERANT TANK AND CELL

Three flight-type titanium generant tanks have completed acceptance test programs at the component level using distilled water instead of the actual generant, hydrazine. This configuration incorporates a fully-ribbed ethylene propylene elastomeric diaphragm. Use of these units will be as originally planned:

first unit	–	Continued use at the subsystem level.
second unit	–	Spare for system testing and future investigations for effects of sloshing and vibration.
third unit	–	To be subjected to the 300°F thermal sterilization test and then long-term storage in the fully loaded service condition; i.e., with hydrazine and gaseous nitrogen at maximum pressure.

The complete development program covering this component is reported in JPL TR 32-865 titled "ALPS Generant Tank and Cell Assembly."

GENERANT CONTROLLER

The development has continued on improving the performance of the current design in two specific areas: hysteresis during instantaneous reversals of stroke and thermal compensation.

The major effort has been concentrated on the problem of minimizing the Belleville spring package friction. Revisions from the original design have reduced the hysteresis; however, this level is not considered best, and investigations will continue in this specific area.

The complete generant controller development program is reported in JPL TR 32-814.

FILL VALVES

This basic design was developed to overcome the deficiency inherent in a conventional needle valve: rotation of the pintle on the seat during closure. The new design incorporates a precision ceramic ball retained in the threaded member that is rotated during the opening or closing cycle. This effort was limited to the development of manual types only in the 1/4- and 1/2-in. line sizes. Service media during testing included gaseous helium and nitrogen, and both propellants N_2H_4 and N_2O_4.

The objectives of the program were met and the complete development progra is reported in JPL TR 32-875.

HEAT EXCHANGER

The original fuel and oxidizer heat exchanger configurations are described in JPL SPS 37-27, Vol. IV; the available exchangers were severely damaged as a resul of three subsystem tests (see JPL SPS 37-35, Vol. IV).

Based on post-test examinations of the records and hardware, both the fuel and oxidizer exchangers were redesigned. The fuel unit, which is more critical, wa provided with a greater cooling capacity from the hot gas to liquid coolant. These ne versions (consisting of two units each) are being fabricated and scheduled for deliver. by February 1966. Testing will be resumed then.

LIQUID AUXILIARY PROPULSION SYSTEMS (731-13)

WARM GAS ACTUATOR SYSTEM DEVELOPMENT

NASA Work Unit 731-13-01-03-55
JPL 331-10401-2-3440
J. C. Randall

OBJECTIVE

The objective of this task is to develop a hydrazine/plenum system for an attitude-control mass-expulsion actuation system. The hydrazine is stored as a liquid under relatively low pressure. The flow of hydrazine is regulated by a valve controlled by the downstream pressure. At the entrance to the plenum, the hydrazine contacts a catalyst bed and decomposes into gaseous nitrogen, hydrogen, and ammonia. The gases are then expelled through conventional valves and nozzles for attitude control. When the plenum pressure drops to a certain pressure, the control valve allows more hydrazine to flow raising the plenum pressure. The chief advantage is that the hydrazine gases have a specific impulse of 115 lb-sec/lb in comparison to 72 lb-sec/lb for nitrogen. Added gains in system weight are also made because of the low pressure hydrazine storage. A typical system is shown in Fig. 1.

STATUS

The Guidance and Control Division has collaborated with the Propulsion Division in the construction of a breadboard hydrazine/plenum attitude control actuation system, started in July 1965, to learn more of the operating characteristics associated with this type of system. A conventional <u>Ranger</u> half distribution system was connected to a gas generator for testing,

The tests performed to date have demonstrated the ability of the gas generator to more than meet the demands of the attitude control system when operated under simulated <u>Voyager</u> conditions. The restart capability has also been partly demonstrated with over several hundred restarts on the particular catalyst bed in use. It has been found; however, that the catalyst bed firings generate particles 50 to 100 μ in size. Because the attitude control jets require cleanliness down to 5 μ in size, it appears that filters will be required for any flight use this system might undergo. Tests are now being conducted on labyrinth filters (large filter area) to check their susceptibility to clogging, which is a real hazard in long-term missions such as <u>Voyager</u>.

It was seen that the catalyst bed had a tendency to pack as the unit was fired. Extreme packing would cause incomplete dissociation of the hydrazine and then lower the efficiency. After many firings, however, it appears that the catalyst bed packing begins to level off at a point that is quite acceptable.

FUTURE ACTIVITIES

To prove the long term capabilities of the hydrazine/plenum system, it is planned to run an isolated 40-day test. During this test, the gas generator will be actuated about the same number of times as a 450-day Voyager mission. The mass flow of hydrazine for a Voyager mission will also be duplicated. Successful completion of this test will establish confidence in this type of system to perform on a Voyager mission.

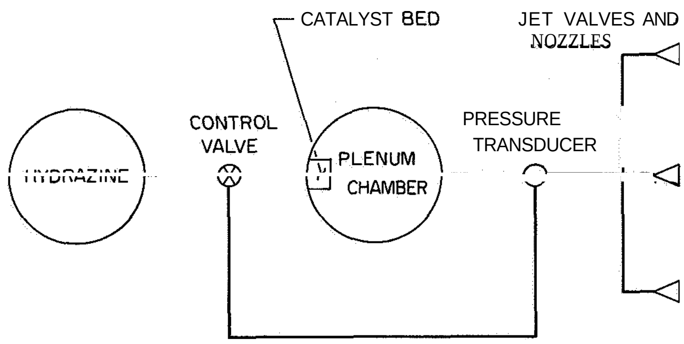

Fig. 1. Hydrazine/plenum system schematic

RESEARCH PROGRAM (129)

FLUID PHYSICS RESEARCH (129-01)

MOLECULAR SPECTROSCOPY

NASA Work Unit 129-01-01-01-55
JPL 329-10101-1-3280

R. Poynter
S. Trajmar

OBJECTIVE

The objective of this task is to use microwave spectroscopy in the study of molecules and free radicals that are in planetary atmospheres or in space. The molecular rotation, spin reorientation, and A doubling energy levels and transitions involved will be studied.

Also, to design and build a low-energy, high-resolution electron impact spectrometer. To obtain data with this instrument on energy levels and transitions in atomic and molecular targets. The cross sections for elastic and inelastic processes involving low-energy electrons and atoms (molecules) will be found.

MICROWAVE SPECTROSCOPY

As preliminary familiarizing experiments that exploit the unique high sensitivity of the microwave spectrometer developed for this task, certain organic molecules are being studied. To understand the nuclear magnetic resonance (NMR) spectrum of 2, 4-dicarbaclovoheptaborance (7), a deuterium exchange reaction was performed. The ^{11}B resonances as observed in the normal molecule are split into doublets. By using ^{1}H substitution, the interpretation of the normal molecule spectrum should be simplified. However, the NMR spectrum of the ^{1}H substituted molecule was itself ambiguous. The difficulties in the NMR assignment were resolved by the study of the microwave spectrum of the partly deuterated molecule. The microwave results showed that the three-ring hydrogen atoms were involved in deuterium substitution, therefore providing an unambiguous assignment for the NMR spectrum.

The microwave spectral analysis of 2, 3-dicarbaclovohexaborane (6) has been completed. The original data on this compound showed that it had the formula $C_2B_4H_6$, but the skeletal configuration was uncertain. The analysis shows that this molecule is very nearly a spherical top, with a dipole moment of 1.50 Debye units determined by Stark effect measurements. By assigning the spectra for six isotopic boron species, the boron atoms have been located in the molecular principal axis frame. The boron-boron bond distances were calculated from this information. Approximate B-C bond lengths can also be calculated, but their accuracy is low. The study of the ^{13}C isotopic species will accurately find the carbon atom locations and the B-C bond lengths.

The chemical preparation of the enriched ^{13}C isotopic species is in process. After synthesis, the molecule will be subjected to microwave spectral analysis. The investigation of this molecule will stop the work on the carborane series.

The compound, 2, 2-difluoropropane, has been synthesized and preparations are being made to find its microwave spectra. Primary interest will focus on the molecule's barrier to internal rotation.

FREE RADICAL STUDIES

During this period, an absorption cell suitable for the microwave spectroscopy of gaseous free radicals has been designed and is being constructed. The absorption cell plate waveguide, the vacuum tank and support, and the main vacuum pump have been obtained. The microwave transition, and the ultra-high vacuum pump have been ordered. A quadrupole gas analyzer is being incorporated into the experimental system both to assist with the expected vacuum problems and to act as a monitor to the experimental parameters in the course of operation.

LOW-ENERGY ELECTRON IMPACT SPECTROSCOPY

Construction of the low-energy, high resolution electron scattering apparatus is continuing. The mounting frame for the scattering chamber and the electron-optical elements have been built. The sample inlet system and the pressure monitoring elements are being assembled.

During the period covered by this report, the Molecular Spectroscopy laboratories were relocated in a new building. The microwave spectroscopy equipment has been reassembled and is now operating. However, because of added electrical and mechanical requirements, the Electron Impact Spectroscopy laborator has not been completed and final assembly of the apparatus must await its completion

PUBLICATIONS DURING THE PERIOD

1. Poynter, R., and Beaudet, X., "The Microwave Spectrum, Structure, and Dipole Moment of 2, 4-Dicarboheptaborane (7)," J. Chem. Phys. Vol. 43, p. 2166 (1965).

2. Poynter, R., Onak, T., Dunks, G., and Beaudet, R., "The NMR and Microwave Spectrum of Some Deutero-derivatives of 2, 4-Dicarboclovoheptaborane (7)," J. Am. Chem. Soc., (to be published).

PLASMA SOURCES, GENERATORS AND ACCELERATORS

NASA Work Unit 129-01-04-01-55
JPL 320-11101-1-3830

Gary R. Russell

OBJECTIVE

The main objective is to produce several types of plasma sources capable of producing large volumes of high-energy, steady-state plasma to be used in the study of transport phenomena, inelastic rate processes, and shock wave structure. A secondary objective is to develop a basic understanding of the operation of non-equilibrium magnetohydrodynamic (MHD) accelerators and generators. Generator and accelerator research is directly related to space power generation, electrical propulsion, and high-energy wind tunnel simulation.

MAGNETOPLASMADYNAMIC SOURCE

Testing of a water-cooled magnetoplasmadynamic (MPD) plasma source, first described by Ducati, Gianinni, and Muehlberger (AIAA Journal, 1964) has continued into the first half of FY 1966. In earlier experiments, the source was operated over a current range of 100 to 4000 amp at argon mass flows of 0.05 to 1.5g/sec. Extensive measurements of the electron density and temperatures were made and reported (Ref. 1). Also, electron temperature profiles adjacent to the MPD arc exit have been determined spectroscopically using the Abel transformation (Ref. 2). The results show that the electron temperature is almost constant between the electrode surfaces, supporting the earlier work (Ref. 1) where an average electron temperature was measured across the arc plume diameter.

During the first half of FY 1966, the operating range was extended to a mass flow of 35g/sec at a total enthalpy of 650 Btu/lb and to an ambient pressure of 1 atmosphere in anticipation of its use as a plasma source for MHD generator studies. At higher pressures and lower currents the self-fields are negligible and the device operates in a conventional electro-thermal mode. The thermal efficiency increased as the feed rate was increased to over 70% at 35g/sec.

A thrust stand has been installed and calibrated in one of the vacuum tanks. Thurst measurements have been made with the MPD source operating with an argon mass flow of 0.5g/sec at 1500 amp. The specific impulse and thrust efficiency at these conditions were 300 sec and 8%, respectively. Low thrust efficiencies at a low specific impulse is typical of the operation of the MPD arc. It is expected that both the efficiency and specific impulse will increase as the mass flow rate is decreased at a constant current level.

Thrust measurements will continue into the last half of FY 1966, and will include tests with other gases than argon, The thrust measurements will be made coincident with plume diagnostics that will include spectroscopic temperature measurements and velocity measurements. The measured thrust and momentum profiles in the MPD plume will be compared to try and determine the magnitude of jet entrainment.

Preliminary experiments with a noncontained MPD source without porous electrodes (i.e., where the stagnation conditions are at ambient pressure) have shown that the source does not operate at constant pressure in the configuration that was used. The shock formation in the exit plume of the noncontained MPD source was still found to be similar to that of the contained arc (Ref. 1), although less obvious. It is believed that electro-magnetic pumping occurs in the region between the electrodes producing a downstream flow very similar to the contained arc. In the last half of FY 1966, the noncontained source will be redesigned to allow the flow to expand in the electrode region to try to prevent shock formation downstream of the source exit. Tests with porous electrodes will not go on until the problem associated with the shock wave formation has been solved.

ACCELERATOR-GENERATOR STUDY

The nonequilibrium computer program has been extended to include inert gas mixtures besides pure inert gases. It is anticipated that the extended program will be completed during the last half of FY 1966. Preliminary results from the program have been used in the design of an experiment to determine the feasibility of operating an MHD generator with pure inert gases and inert gas mixtures. Pure argon, helium-xenon, and argon-xenon mixtures will be used as generator working fluids.

A clustered MPD arc heater, an uncooled tantalum supersonic nozzle, and a constant area and constant pressure generator test section will be used in the steady-state generator tests. The fabrication of the arc heater has been completed in the first half of FY 1966. The heater is designed to produce 100g/sec of argon at a stagnation temperature of 2500°K. The tantalum nozzle and generator test section have been designed and are now being fabricated. Preliminary generator tests will begin in the third quarter of FY 1966.

The generator test section is designed so that it can be used as an accelerator or generator. On completion of the initial generator tests, measurements will be made of the operating characteristics of a segmented accelerator using inert gas mixtures and compared with the nonequilibrium theory.

REFERENCES

1. Kelly, A. J., Nerheim, N. M., Gardner, J. A., "Electron Density and Temperature Measurements in the Exhaust of an MPD Source," AIAA 2nd Annual Meeting and Technical Demonstration, July 26-29, 1965, San Francisco, California, (also, AIAA Journal, February 1966).

2. Nerheim, N. M., "Spectroscopic Measurement of Plasma Electron Temperature During the Relative Intensities of Argon II Lines," JPL SPS 37-35, Vol. IV,

MAGNETO-FLUID DYNAMICS

NASA Work Unit 129-01-05-02-55
JPL 329-10801-1-3270

T. Maxworthy
G. Yonas
R. Peyret

OBJECTIVE

The objective of this task is to improve our understanding of both the effect of magnetic fields on the flow of conducting fluids and the somewhat analogous effect of rotation on various types of flow.

ROTATING FLUIDS – T. Maxworthy

The Taylor Problem

The measurements of the drag on a sphere as it moves through a rotating fluid have been completed. These show that at large T the drag depends only on the interaction parameter S, being like S^2 for moderate S and like S for large S. Velocity measurement in the forward wake, using the hydrogen bubble technique, shows a characteristic slug that varies rapidly in length as S increases from about unity but reaches an asymptotic length, depending only on T, as S approaches 10. Attempts have been made to measure the rotation rate of the slug to find the pressure distribution within it and its contribution to the total drag. Success has been limited so far, but an improved multiple pulsing method should improve accuracy considerably. A report on this work is in its initial stages.

Two papers have been published: "Accurate Measurements of Sphere Drag at Low Reynolds Number," J. Fluid Mech., Vol. 23, No. 2, October 1965, and "An Experimental Determination of the Slow Motion of a Sphere in a Rotating, Viscous Fluid," J. Fluid Mech., Vol 23, No. 2, October 1965.

ROTATING BOUNDARY LAYER – T. Maxworthy

The flow created by a disk rotating in a cylindrical housing has been studied in some detail. Most of the flow comes to a rotation rate about 0.3 times the rotation rate of the disk. The rotation rate close to the center is considerably smaller than this. An improved apparatus design featuring an independently rotating side wall has been constructed to study the reasons for this difference. The boundary layer created on the stationary wall, away from the central region, has all the characteristics of the Bödewadt solution, with radial and tangential velocity profiles that oscillate in magnitude in the axial direction.

The flow created by a laboratory tornado rotating over a stationary surface has been observed. Most of the flow that goes into the core of the tornado comes from the bottom boundary layer. The rotation outside the core is not of the "potential vortex" type but actually has a considerable region of constant tangential velocity. The boundary layer associated with this outer flow is not in agreement with the theoretical calculation, because an axial flow is also superimposed on the boundary layer by the outer flow (an effect not included in the numerical calculation).

LIQUID SODIUM TUNNEL – T. Maxworthy and G. Yonas

Drag measurements for 1/4-, 1/2- and 3/4-in. diameter spheres and disks have been completed. Strange behavior of the "no magnetic field" drag led to a secondary program of flow visualization in a wind tunnel to see if wall boundary layer separation was important. It was found to be nonexistent. Finally, a calibration of the electromagnetic flowmeter at lower flows than the earlier calibration showed an unexpected nonlinear behavior, presumed caused by secondary flows in the meter. When the corrected velocities are applied to the drag data, all difficulties disappear and the data are quite consistent.

The design of the sphere, around which we are to measure the pressure distribution, has involved mechanical problems that are now essentially solved. In the meantime, a 1/2-in. diameter disk has been added to the nose of the 1/8-in. Pitot tube and measurements of its front stagnation pressure were made. At moderately large values of interaction, parameter increases in pressure over the dynamic pressure (Q) were found. Nowhere were these larger than 0.2Q, and by themselves cannot account for the drag increases measured earlier.

FLOWS IN A DUCT WITH A NONUNIFORM MAGNETIC FIELD – R. Peyret

A JPL report (TR 32-871) and a paper for publication in the open literature on a linearized solution of the tunnel exit problem are in the last stages of preparation.

Two reports on the flow of a compressible, electrically conducting fluid in a traveling hydromagnetic wave tube have been published in Comptes Rendus Acad. Paris, Vols. 261 and 262.

SHOCK-HEATED PLASMAS AND JET STRUCTURE

NASA Work Unit 129-01-05-03-55
JPL 329-11301-2-3270
H. I. Ashkenas
D. A. Russell

OBJECTIVE

The objectives of this task are to study and develop techniques and flows for use in plasma-dynamic and aerodynamic investigations.

JET STRUCTURE

Rotational spectra along the centerline of the electron beam-excited nitrogen free-jet have been obtained for a wide variety of conditions. Three orifice diameters have been used; each of these has been operated over at least a tenfold range of stagnation pressures. Data have been obtained for Reynolds numbers, based on sonic conditions at the orifice, that range between 100 and 5000. Some rotational freezing has been seen at the very lowest Reynolds numbers. The rotational temperatures derived from the measured spectra appear to be consistently higher than the translational temperature calculated for inviscid, isentropic flow. While this result appears to be consistent with that of other investigators, the exact anomaly is unclear; i.e., are the higher measured temperatures an inherent failing of the spectroscopic technique or do they represent an actual rotational temperature lag? This question is being actively pursued.

SHOCK-WAVE STRUCTURE

It is proposed to obtain velocity distribution function information by measuring the Doppler profile of radiation scattered off a column of excited gas atoms. An experiment has been set up to study the resonant scattering of an external radiation source from gas atoms that have been excited by a low-voltage electron beam. Scattering of 10,829 Å helium radiation off the 2^3S metastable state in helium has now been measured with the aid of phase-lock detection techniques (see Fig. 1). The sensitivity of the experiment is being improved to obtain information on other promising lines. A water-cooled, flowing-gas, discharge tube has been built to replace the sealed capillary discharge tubes used earlier as external light sources. Further large gains in sensitivity are expected with the development of a high-current electron gun.

SHOCK-STRENGTHENING BY AREA CONVERGENCE

The CIT 17-in. diameter shock tube was coupled with a 10° conical section to a 1-in. diameter tube. Measurements showed that the shock wave as much as tripled its velocity on reaching the entrance to the smaller tube. Second-order wave interactions then caused it to decay in strength as it progressed downstream. This motion has been studied in detail, including viscous and real gas effects. The results are being prepared for publication. Preliminary results were presented in JPL SPS 37-36, Vol. IV.

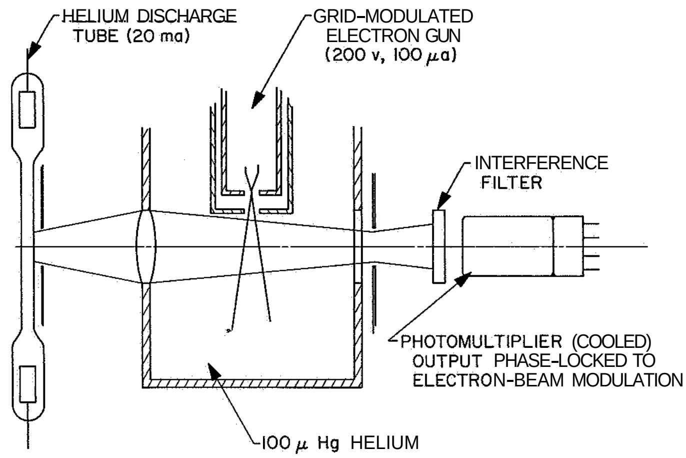

Fig. 1. Schematic of experiment for scattering of 10,829 Å helium radiation off 2^3S metastable state in excited helium

PLASMA TRANSPORT PROPERTIES, SHOCK WAVES, AND INELASTIC RATE PROCESSES

NASA Work Unit 129-01-05-04-55
JPL 329-11201-1-3832

Gary R. Russell

OBJECTIVE

The overall objective is to experimentally study transport phenomena, shock wave structure, and inelastic rate processes in partially ionized gases. Particular attention is focused on the nonequilibrium plasma where radiation can play an important role in the inelastic rate processes, and plasma instabilities can contribute to anomalies in the transport properties. This research is directly related to the development of electrical propulsion devices, magnetohydrodynamic (MHD) generators and high temperature wind tunnel simulators that operate almost entirely in a region where the working fluids (partially ionized gases) are not in equilibrium.

Determining shock structure, measurement of electron recombination rates, and the measurement of ionization rates in inert gases will be emphasized in FY 1966.

ELECTRON RECOMBINATION RATES

Work with fast pressure gauges has been continued in the first half of FY 1966. It has been found that a pressure gauge with a rise time of better than 100 μsec at a pressure of the order of 1 mm Hg cannot be successfully shielded from the initial electrical discharge in the discharge tube. Therefore, work was begun on the development of a hot wire temperature gauge to measure the atom temperature directly. This gauge has been designed and fabricated, and (after calibration) will be tested in the discharge tube. If this gauge can be successfully shielded, it will be used to measure the transient atom temperature in the recombination rate experiments in the second half of FY 1966.

The "time of flight" Bendix Mass Spectrometer was received in November 1965. The associated apparatus necessary to use it in conjunction with the discharge tube is now being fabricated. After Mass Spectrometer-discharge tube set-up, electron recombination experiments will be resumed, concentrating on the regime in which dissociative recombination may be important.

SHOCK WAVE STRUCTURE

The shock wave holder and water cooled laser assembly, which will be used in the measurement of shock wave structure, have been designed and are now being fabricated. The shock structure experiments will be started (probably in the last quarter of FY 1966) when the Thomson scattering feasibility study is completed, and when a supersonic plume can be produced with the magnetoplasmadynamic (MPD) arc at low pressures. It is thought that the flow is supersonic at low pressures because the visible shock wave at the MPD arc exit disappears; but, so far, there has been no direct experimental evidence of the disappearance of the shock wave. In the third quarter of FY 1966, direct velocity measurements will be made with a laser beam (see section dealing with plasma diagnostics, Task Number 129-01-05-04-55) that, together with determining the total enthalpy by a heat balance of the MPD arc, will make it possible to determine the Mach number of the MPD plume.

LASER INDUCED IONIZATION

A giant-pulsed 100 Mw laser has been used to ionize argon over a pressure range of from 1 to 760 mm Hg. Measurement of the temporal variation of the plasma conductivity with electrostatic probes in the range where the electron density is directly proportional to the electrical conductivity makes it possible to calculate the ionization rate and the time to approach complete ionization of the gas. It has been found experimentally that the ionization rise time is much longer than the laser discharge time when the gas pressure is below 1 atmosphere.

An ionization estimate has also been made based on the assumption that some preexisting electrons gain energy from the laser radiation through inverse Bremsstrahlung processes and ionize the gas by excitational collisions with the gas atoms. By using the concept of the mutual absorption coefficient for the photon-electron interaction given by Wheeler and Wildt (Ref. 1), the elastic and excitational collision cross-section given by Massey and Burhop (Ref. 2), and assuming the rate of ionization to be limited by the rate of excitation to the first excited state, the electron density as a function of time has been computed for a range of pressures. The results are in qualitative agreement with the experimental data and show the same pressure dependence. The possible production of a few high-energy electrons by photon ionization, which ionize the gas by impact without the inverse Bremsstrahlung process, can be excluded by cross-section considerations. It is therefore concluded that the ionization process in the argon gas irradiated by a laser beam is inverse Bremsstrahlung and electron inelastic collisions. The evidence supporting the electron impact process in high pressure gases has recently been published in Ref. 3. The complete details of this work will be available in Ref. 4.

REFERENCES

1. Wheeler, J. A., and Wildt, R., J. Astrophys., Vol. 95, p. 282, 1942.

2. Massey, H. S. W., and Burhop, G. H. S., Electronic and Ionic Impact Phenomena, Oxford Clarenden Press, England, p. 77, 1952.

3. Gill, D. H., and Dongal, A. A., Phys. Rev. Letters, Vol. 15, p. 845, 1965.

4. Chen, C. J., "Experimental Evidence of Inverse Bremsstrahlung and Electron Impact Ionization in Low Pressure Argon Ionized by a Giant-Pulse Laser," (submitted to Physical Review Letters).

PLASMA DIAGNOSTICS

NASA Work Unit 129-01-07-01-55
JPL 329-11401-1-3830
Gary R. Russell

OBJECTIVE

The overall objective is to develop the capability of independently measuring all the thermodynamic, radiative, and kinematic variables of a partially ionized gas that is not necessarily in equilibrium. In FY 1966, measurements of the electron density and plasma velocity are emphasized using several independent techniques.

MAGNETIC VELOCITY PROBE

Preliminary experiments were conducted in a shock tube operated by the Aerodynamics Facility Section with a probe similar to that used earlier to measure the velocity of the magnetoplasmadynamic (MPD) source. The experiments were made with magnetic fields less than 40 gauss and with a 1/2-in. separation between the two pins of the probe. The resulting U x B signal was low and largely masked by precursor signals that arrived at the probe before the arrival of the shock front.

After scheduling the shock tube experiments, reports of a probe using an ac magnetic field were published (Ref. 1). The ac probe operates with fields as low as 1 gauss and, therefore, does not disturb the plasma as much as do the larger fields required for the dc probe. Then, the problems associated with the variation of the probe work function that limit the usefulness of the dc probe are eliminated. Because of these advantages, the work with the dc probe has been stopped and a probe using an alternating magnetic field will be used in the future.

SPECTROSCOPIC DIAGNOSTICS

Since the publication of Ref. 2, in which the reported electron temperatures were determined from measurements along a single line of sight through the plume, lateral profiles of the intensity of a number of argon II lines have been obtained. The lateral profiles were inverted with Abel's formula to obtain radial intensity distributions from which temperature profiles were found. The results are reported in Ref. 3. It was found that the temperature profiles were nearly flat and, therefore, agreed closely with the average temperature determined from measurements made along a single line through the plume.

MICROWAVE DIAGNOSTICS

During the first half of FY 1966, the swinging microwave diagnostic probe was much improved insofar as its electron density sensitivity range was increased from ~ 7:1 to approximately 100:1. This was done (at K-band, 24 gHz) by modification of the basic circuitry. The initial versions of the probe allowed measurements of the amplitude of the microwave signal propagated through, and reflected from, the plasma delineated by the gap formed by the quartz plates over the transmitters and receivers horn apertures to be made. The new circuit, designed to operate under conditions of the high vacuum (and at the same frequency), permits the measurement of three parameters: the measurable transmitted phase, the measurable reflected phase, and (for comparison) the transmitted signal amplitude. The measurable phases, i. e., the vector sum of the wave transmitted through (or reflected from) the plasma and a reference wave, require less involved circuitry than the measurement of pure phase shift because of the presence of the plasma; but has about the same electron density sensitivity. More than 500 tests have shown that this system is rugged, reliable, and can be used for the rapid acquisition of electron density profile data.

Development of a 90 gHz (3. 3 mm wavelength) diagnostic circuit has progressed well. The basic power supply has been checked out, and shown to provide 29 mw (cw) of RF energy at the desired frequency of 90 gHz. Most of the components necessary for the fabrication of a swinging diagnostic probe operating at this frequency are now being incorporated into a prototype circuit for this arm. The circuitry is designed to be readily interchangeable for use either in the vacuum plasma facility (i.e., on a swinging arm) or for use with a high purity "kinetic" shock tube.

LASERS

A giant-pulsed 100 Mw laser has been used to measure the velocity of both un-ionized and partially ionized gas flows. The laser is focused at a focal point by a lens outside the gas flow. In about 20 nanoseconds, the gas in a volume of 10^{-5} cm^3 in the flow is completely ionized. The motion of this luminous ionized gas is detected by a high-speed motion picture camera. In this way local velocity distributions can be measured in complex flow fields without disturbing the flow.

Velocity profiles have been measured in un-ionized supersonic gas jets produced by a supersonic nozzle, and compared with conventional pitot tube measurements assuming an isentropic expansion in the supersonic nozzle. The two methods differ by about 5%. It is thought now that the laser measurement is more accurate. Comparison with an ac magnetic velocity probe measurement will be made in the last half of FY 1966, using a partially ionized gas produced by an MPD arc, The details of the laser technique and the velocity measurements are to be presented in Ref. 4.

LANGMUIR PROBES

No added work with Langmuir probes has been tried during the first half of FY 1966 because of manpower shift to the microwave work. Inthelast half of FY 1966, the work originally planned for the first half will be carried out: i. e., square wave heating of probe elements, and extension to the measurement of electron densities and temperatures in high pressure flows.

REFERENCES

1. Cason, C. , "Gas Velocity Probe for Moving Ionized Gases," J. Appl. Phys. Vol. 36, p. 342, February 1965.

2. Kelly, A. J., Nerheim, N. M., Gardner, J. A., "Electron Density and Temperature Measurements in the Exhaust of an MPD Source," AIAA 2nd Annual Meeting and Technical Demonstration, July 26 – 29, 1965, San Francisco, Calif., (also AIAA Journal, February 1966).

3. Nerheim, N. M., "Spectroscopic Measurement of Plasma Electron Temperatures Using the Relative Intensities of Argon II Lines," JPL SPS 37-35, Vol. IV.

4. Chen, C. J., "Experimental Study of Breakdown Phenomena in an Argon Gas by a Laser Beam at Very Low Pressure," to be presented at the AIAA Plasmadynamics Conference, Monterey, Calif., March 2 – 4, 1966.

CONTINUUM FLUID DYNAMICS

NASA Work Unit 129-01-09-01-55
JPL 329-10201-1-3270

F. R. Hama
J. M. Kendall, Jr.

OBJECTIVE

The objective of this task is to advance our understanding of those important and still outstanding problems in fluid mechanics: flow stability, turbulence, and separation.

BASE PRESSURE AND SEPARATED FLOW – F. R. Hama

Experimental investigations during the reporting period were on the measurement of the surface pressure over a wedge and of the pressure-recovery distribution along the wake centerline of the wedge, in the same Mach number (2.0 - 4.5) and Reynolds number (0.2 - 2.0 x 10^6) ranges as for the wedge-splitter plate configuration reported earlier.

The base pressure of the wedge was found to be only slightly smaller than a backward-facing step of comparable geometry. The distinct overshoot in the pressure-recovery distribution reported in the earlier progress report is now attributed to an interaction between the lip shock and the recompression shock. Preliminary analysis of the data shows that the lip shock from the wedge is stronger than with the splitter plate.

At Mach numbers higher than 3.5, the pressure distribution on the base face showed a sharp drop immediately behind the separation edge. This suggests that the flow might have turned sharply around the edge and then separated. The immediate schedule calls for the study of the effect of various separation-edge shapes (such as a knife edge, rounded edges, and boat-tails) on the base pressure as well as on the formation of the lip shock. Also planned is a Pitot survey of the near wake field with particular interest in finding the strength of the lip shock, which was already estimated from the shock wave angle to be large.

WAKE STABILITY AND TRANSITION – J. M. Kendall, Jr.

Progress on this experiment was limited because the tunnel was available only 4 days during the half-year. Three-dimensional artificial fluctuations consisting of spanwise variation of amplitude or phase and streamwise vorticity interacting with two-dimension fluctuations were studied during this time. These fluctuations were found to amplify at a rate equal to that of purely two-dimensional waves, and produced large amplitude laminar motion rather than turbulence. Then, the transition that occurs spontaneously at lower supersonic Mach numbers was studied. Spectral energy development and total fluctuation energy distribution throughout the transition region were recorded.

BOUNDARY LAYER STABILITY – J. M. Kendall, Jr.

A preliminary experiment on compressible boundary layer stability was added to as part of the wake stability and transition test. The glow-discharge technique was used for generating two-dimensional disturbances of controlled frequency in the laminar boundary layer on the floor of the tunnel at Mach = 3.7. Because the boundary layer was not steady and showed incipient transition, measurement of the stability characteristics was impossible. However, the test showed some promise because fluctuations within a certain frequency range were greatly amplified. A 6-ft long boundary layer plate has been prepared for forthcoming tests to try to obtain steady flow conditions.

FACILITY – J. M. Kendall, Jr.

A low-turbulence wind tunnel has been constructed and is in the final stage of assembly. It is made of aluminum and is 35 ft long. A 36-in. axial blower driven by a 15 HP motor is expected to produce air speeds exceeding 70 ft/sec in the 2-ft square test section. The test section floor is adjustable to control pressure gradients, and is removable for replacement with a traveling-wave flexible wall planned for experiments on wind-wave interaction.

SUPERFLUID HELIUM FLOW – J. M. Kendall, Jr.

A limited effort to develop a pressure transducer for recording liquid helium Pitot pressure was made. The results were not encouraging.

STABILITY OF THE COMPRESSIBLE, LAMINAR BOUNDARY LAYER – L. M. Mack

For free-stream Mach numbers greater than about 3.5, the inviscid theory has proven to be ample to obtain most of the stability characteristics of the laminar boundary layer. Therefore, the inviscid theory has been used to extend the earlier work in two directions. First (as reported in JPL SPS 37-35, Vol. IV), the time rates of amplification for both the insulated and highly cooled boundary layers have been computed at free stream Mach numbers of 8 and 10. Second, the restriction to two-dimensional disturbances has been dropped and (as reported in JPL SPS 37-36, Vol. IV), amplification rates have been obtained as functions of the wave angle, which is the angle between the wave normal and the free-stream direction.

As the Mach number increases, there is a wider range of unstable wave numbers and some of the modes merge together. For example, as shown by Fig. 1, the first four modes at free stream Mach 10 form a single unstable region for the insulated-wall boundary layer. At this Mach number it is no longer possible to completely stabilize the first mode by cooling the wall. Cooling destabilizes the higher modes and separates the merged modes. Therefore, the frequency response of the cooled-wall boundary layer is much more selective than for the insulated-wall boundary layer.

Two-dimensional disturbances, which are the most unstable for the incompressible boundary layer, may be more stable than three-dimensional disturbances for the compressible boundary layer. By the Dunn-Lin transformation, inviscid numerical solutions for oblique waves can be obtained from the same computer program used for two-dimensional solutions. Maximum amplification rates of oblique disturbances for the first two modes at four Mach numbers are shown in Fig. 2. The most unstable first-mode disturbances have a wave angle of between 50 and 60 deg. However, for the second-mode, the two-dimensional disturbances are more unstable than the three-dimensional disturbances, and are the most unstable of all disturbances of any mode and any wave angle.

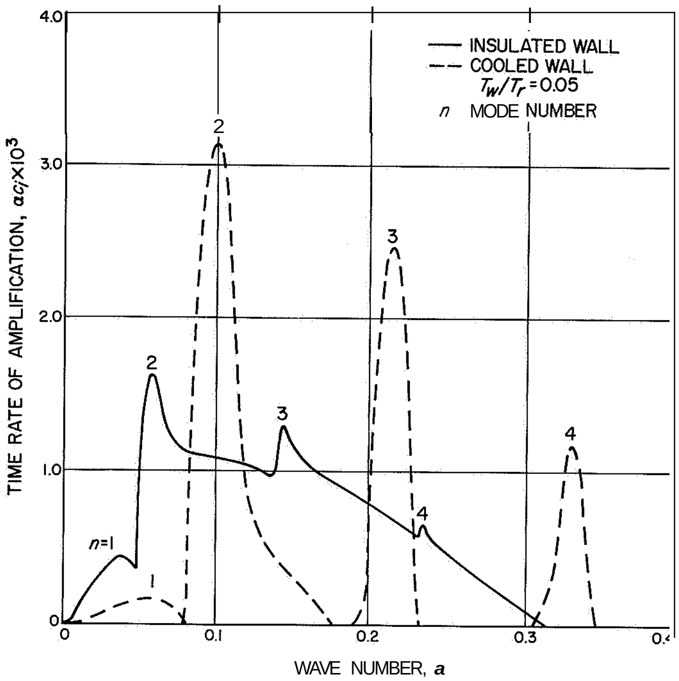

Fig. 1. Time rate of amplification vs wave number for first four modes for insulated wall and cooled wall (free-stream Mach 10)

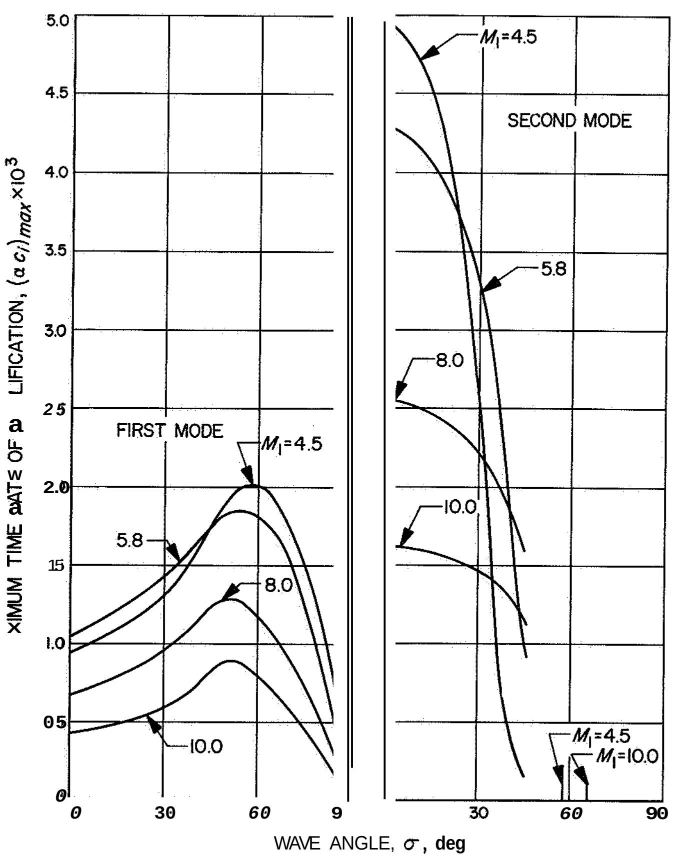

Fig. 2. Effect of wave angle on maximum time rate of amplification of first and second modes at free-stream Machnumbers 4.5, 5.8, 8.0, and 10.0

PLASMA HEAT TRANSFER

NASA Work Unit 129-01-09-04-55
JPL 329-10701-1-3831
Paul F. Massier

OBJECTIVE

The general objective of this task is to contribute to the understanding of convective and radiative heat transfer from ionized gases flowing under the influence of pressure gradients, applied magnetic fields, and applied electric fields. The objectives for the current fiscal year are to: (1) compare the magnitudes of the convective and radiative heat transfer rates from thermally ionized argon flowing at subsonic velocities, (2) evaluate convective heat transfer from thermally ionized argon flowing at supersonic velocities in adverse pressure gradients, (3) complete the installation of the test facility that will be used to evaluate the influence of electric and magnetic fields on heat transfer from ionized gases and obtain preliminary results with applied magnetic fields, (4) establish conditions for which a radiatively cooled nozzle can be used to accelerate ionized argon to supersonic velocities, (5) establish a theoretical model and perform experiments on compressible swirling flow through a supersonic nozzle, and (6) program on a digital computer an analysis that has been made for the compressible quasi two-dimensional flow of an ionized gas without swirl through a supersonic nozzle with heat transfer.

COMPARISON OF CONVECTIVE AND RADIATIVE HEAT TRANSFER

Preliminary experiments using an uncooled hohlraum have shown that the total radiation from ionized argon in the mixing chamber region (Fig. 1) is about 2% of the convective heat flux at stagnation pressures from 1.0 to 4.0 psia at free stream Reynolds numbers up to about 400 and a temperature of about 7500°K as determined spectroscopically. These hohlraum results were obtained by neglecting the existence of the hohlraum quartz window in the analysis of the data. Details are given in Ref. 1. Simultaneous hohlraum and spectroscopic measurements in the mixing chamber are being continued. The effect of the quartz window is now under analytical investigation and indications are that the actual radiation heat flux was even less than the 2% obtained by ignoring the window.

Determining the enthalpy profiles has not yet been done, but may be tried during the next report period.

SUPERSONIC VELOCITIES WITH ADVERSE PRESSURE GRADIENTS

Numerous experiments have been performed to measure the convective heat transfer and wall pressure distributions along a constant-diameter duct containing supersonic flow of ionized argon with an adverse pressure gradient. An analytical model is now being sought that will help explain the results. This type of flow field is generally complicated by the existence of a series of oblique and normal shock waves that form to accommodate the imposed pressure gradient. These waves may react with the boundary layer to produce local heat fluxes that differ from those predicted using a shock-free assumption.

TEST FACILITY FOR APPLIED MAGNETIC AND ELECTRIC FIELDS

Preliminary checkout has been started on the test stand that will be used to determine the influence of applied magnetic and electric fields on convective heat transfer from ionized gases. Initial tests will be conducted using an axisymmetric nozzle that is cooled only by radiation to minimize thermal boundary layer thickness. It is anticipated that a magnetic field will be applied normal to the flow during the latter part of the next 6-mo period.

SWIRLING FLOW THROUGH A NOZZLE

Analysis of an added experiment of compressible swirling flow at a stagnation pressure of 2.0 psia without external heat transfer through a supersonic nozzle was completed. In JPL TM 33-243, results at a pressure of 15.2 psia were discussed. In these experiments argon was used at about 70°F stagnation temperature. This investigation was undertaken to aid in the understanding of swirling flows such as those that are commonly used to help stabilize arc jets. Swirl can have a large influence on convective heat transfer as was discussed in JPL TM 33-243. At the lower stagnation pressure, the ratio of the tangential to axial velocity at the nozzle inlet was less, as shown in Fig. 2, and this prevailed throughout the nozzle. Details of this investigation, including the analysis, appear in Refs. 2 and 3.

It was also demonstrated that swirl can cause a large reduction in axial thrust. The distribution of thrust along a nozzle with swirl to thrust without swirl for one test at a stagnation pressure of 15.2 psia is shown in Fig. 3. A discussion of the thrust results may be found in Ref. 4.

Also, pressure drop results for swirling flow in a constant-diameter duct were obtained simultaneously with the nozzle experiments and these results are given in Ref. 5.

TWO-DIMENSIONAL NOZZLE FLOW WITHOUT SWIRL

The digital computer program for quasi two-dimensional equilibrium flow of an ionized gas through a supersonic nozzle with convective heat transfer has been essentially completed and preliminary cases are now being investigated. The problem of a singularity at the nozzle throat does not occur because experimental wall static pressures and heat fluxes are used as boundary conditions. The computed variables include velocities, ionization fractions, temperatures, densities, etc. as the flow expands through the nozzle. During the next reporting period it is anticipated that results will be obtained at various nozzle inlet conditions.

REFERENCES

1. Roschke, E. J., "Thermal Radiation From Ionized Argon as Determined by Application of Near-Black Cavities," JPL SPS 37-36, Vol. IV, pp 57-92, December 31, 1965.

2. Massier, P. F., "Axisymmetric Steady Flow of a Swirling Compressible Fluid Through a Convergent-Divergent Nozzle Without External Heat Transfer," JPL SPS 37-33, Vol. IV, pp 133-141, June 30, 1965.

3. Massier, P. F., "Swirling Flow of Argon Through An Axisymmetric Convergent-Divergent Nozzle," JPL SPS 37-34, Vol. IV, pp 149-157, August 31, 1965.

4. Massier, P. F., "Thrust Comparisons for Swirling and Nonswirling Flows of Argon Through a Convergent-Divergent Nozzle as Determined From Wall Pressure Measurements," JPL SPS 37-35, Vol. IV, pp 161-165, October 31, 1965.

5. Massier, P. F., "Static Pressure Drop Along the Wall of a Constant-Diameter Duct Which Contains a Decaying Swirling Flow of Argon," JPL SPS 37-36, Vol. IV, pp 117-124, December 31, 1965.

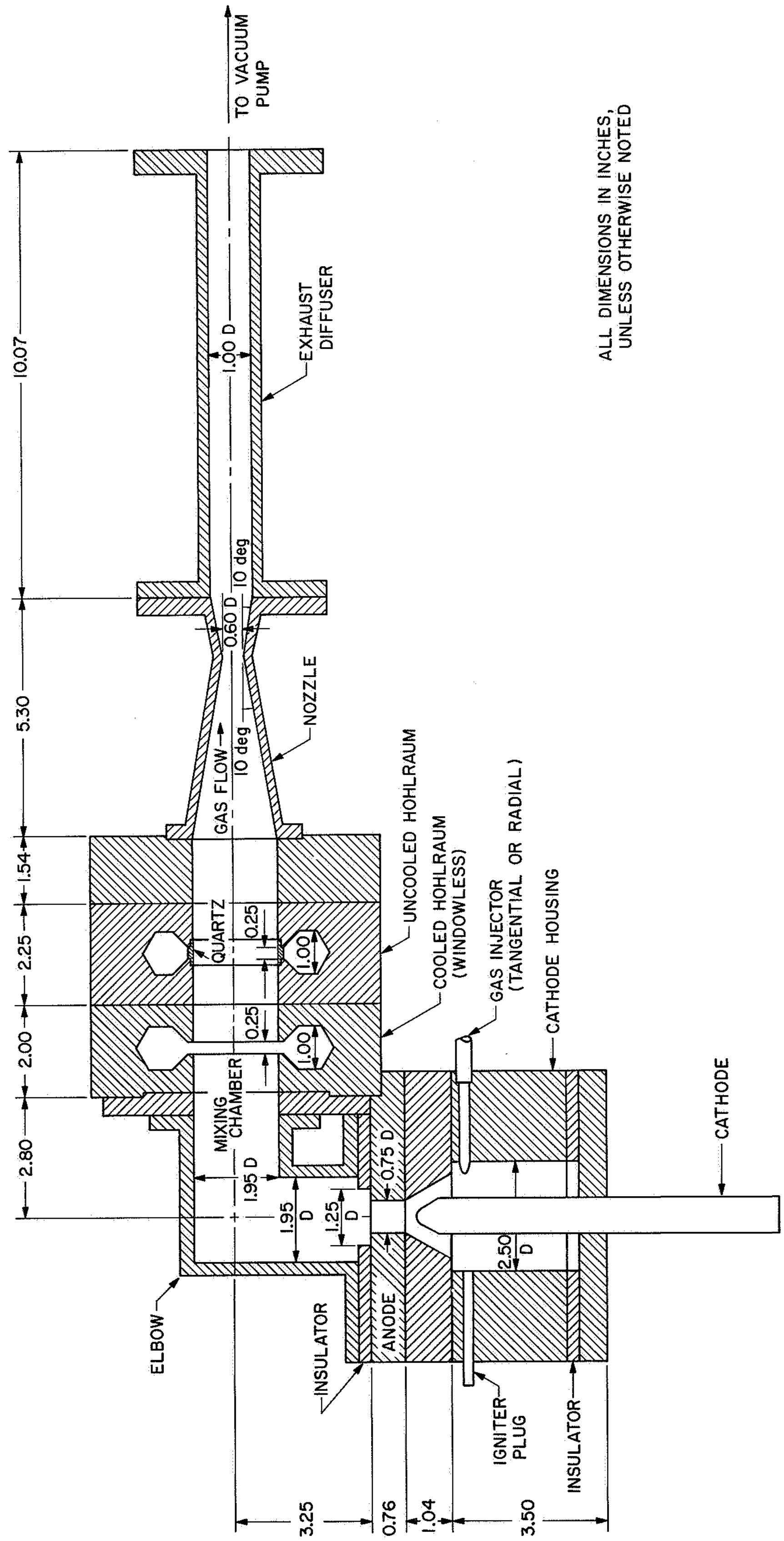

Fig 1 Plasma heat transfer test apparatus

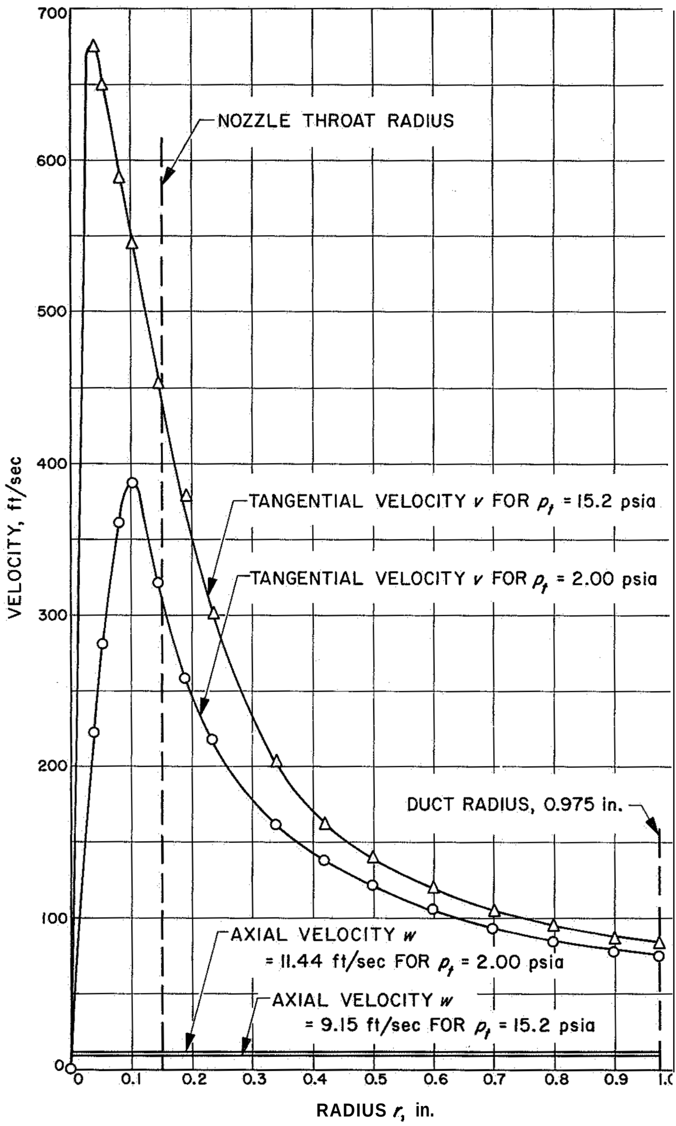

Fig. 2. Comparison of radial distributions of tangential and axial velocities at nozzle inlet

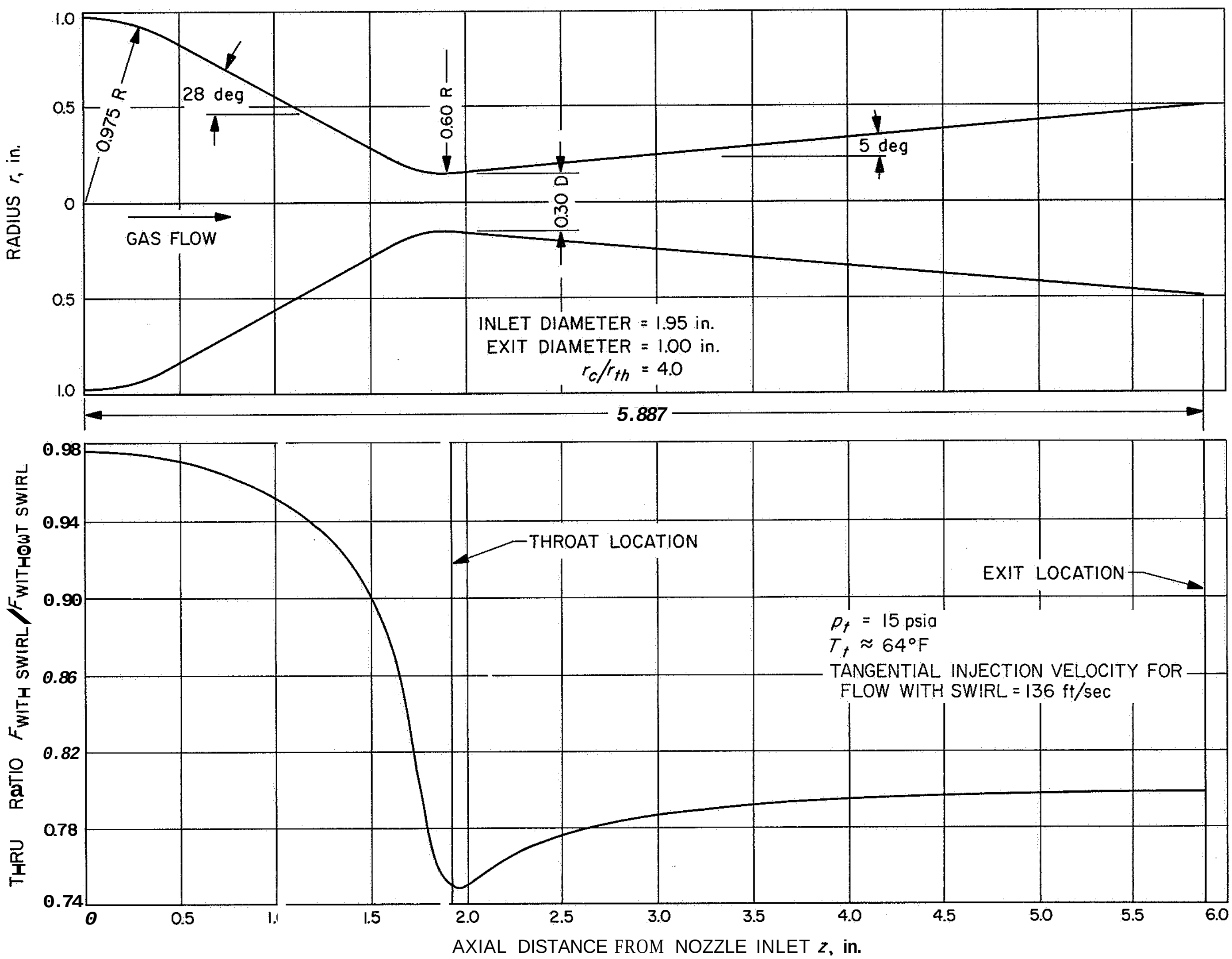

Fig. 3. Distribution of ratio of thrust with swirl to thrust without swirl for argon flow through convergent-divergent nozzle

RAREFIED GAS DYNAMICS
NASA Work Unit 129-01-10-01-55
JPL 329-10501-1-3270

R. E. Center
M. T. Chahine
W. H. Christiansen
D. A. Russell

OBJECTIVE

The objective of this task is to advance our understanding of low density phenomena by carrying out a coordinated theoretical and experimental investigation of shock structure and other low density gas and plasma flows.

SHOCK WAVES IN BINARY MIXTURES – R. E. Center

Using helium-argon mixtures, preliminary measurements have been made of the individual component density in a binary mixture shock wave. A high energy electron beam is injected through the shock wave, and the resulting gas fluorescence is detected with a highly collimated photomultiplier. By suitable choice of narrow band filters, it is possible to measure radiation from each component.

These initial measurements show a large separation of the two components in the shock wave over a wide range of mole fractions of the two gases. Relating static calibration of the equipment to experimental results has been difficult, possibly because of a "halo" caused by secondary electrons. A separate investigation has been made of the halo effect to find which spectral lines are excited by secondary electrons, and several promising lines have been selected for future experiments. It has also been seen that nitrogen forces are excited and may cause a large background signal near the strong argon line originally selected for the measurement. It is thought that this nitrogen band is excited by helium metastables, and the neighboring argon line will be avoided in this experiment.

NUMERICAL SOLUTION OF THE BOLTZMANN EQUATION – M. T. Chahine

The earlier discussed attempt for the solution of the complete Boltzmann equation for a real gas has been temporarily abandoned because we were not able, with our present understanding of the Boltzmann equation, to get the 10% accuracy needed to carry the comparison with the corresponding Bhatnagar-Gross-Krook (BGK) equation.

The present phase of reasearch assumes a two-dimensional (2D) gas in which molecules are restricted to move in two directions only. The transport properties, as well as the general behavior of this gas, have been evaluated. The resulting 2D Boltzmann equation retains many of the characteristic features of the three-dimensional case in a relatively simple way. Several transformations have been worked out with which a suitable numerical accuracy can be obtained.

SEEDED-GAS PLASMA STUDIES – W. H. Christiansen

The cesium boiler and injector have been redesigned and the new construction is almost complete. Using this boiler should give a more steady and spacially uniform distribution of cesium vapor in the carrier gas. Also, a 24 kMc microwave device is being assembled and will be used to obtain an independent measurement of electron densities in the jet.

The procurement of a magnet has been started. This magnet will be used to study the effect of fields on the output of a Langmuir probe immersed in a flowing. ionized gas.

The results of the work on the shock structure in the seeded gas were presented at the September 1965, American Physical Society meeting held in Hawaii.

EXPERIMENTAL STUDIES OF THE MERGED SHOCK-LAYER – D. A. Russell

Measurements are being made of the density distribution along the stagnation streamline of spherical models in a supersonic, low-density, argon stream. A 10 kv electron beam is shot out through the nose of the model and the resulting gas fluorescence is used to obtain density profiles. A Reynolds number range of 20 has been obtained by varying the stagnation pressure and by using 1- and 1/4-in. diameter models. The flow disturbance is seen to extend more than a body diameter upstream at the lowest Reynolds number. The models are now being run with thermocouple instrumentation and water or liquid-nitrogen cooling. A problem in obtaining a consistent fluorescence-density relationship has come up, presumably caused by the beam halo created by secondary electrons. This is being studied further.

HEAT TRANSFER AND FLUID DYNAMICS IN ACCELERATING AND DECELERATING FLOWS

NASA Work Unit 129-01-12-01-55
JPL 329-10401-1-3831

Paul F. Massier

OBJECTIVE

The objectives of the project are (1) to gain an understanding of convective heat transfer and flow phenomena in accelerating and decelerating flows; (2) to correlate experimental results; and *(3)* to appraise existing prediction methods and, where necessary, develop improved prediction methods. During FY 1966, emphasis is placed on turbulent free-stream flows in two axisymmetric convergent-divergent nozzles that have different configurations, in a supersonic diffuser attached to the exit of one of these nozzles, and in the thermal entrance region of a constant diameter cooled approach duct.

45-15-DEG NOZZLE

Testing of the 45-15-deg nozzle, for which heat transfer and wall pressure distributions were reported in July 1965, has continued. Besides earlier tests at a stagnation temperature of 1500° R and over a stagnation pressure range from 30 to 250 psia, tests at 1000 and 2000° R have been made with a cooled approach duct that provided a nozzle inlet turbulent boundary layer thickness of about 0.45 of the inlet radius. The effect of inlet boundary layer thickness was investigated by removing the approach duct that resulted in a thin boundary layer about 0.02 of the inlet radius. A sample of these results are shown in Figs. 1 and 2 in terms of the variation of the heat transfer coefficient along the nozzle. Added data were shown and discussed in the JPL Annual OART Research Program Review, October 11 – 12, 1965. A portion of this data was given in Ref. 1. Reports will be written on the unusual flow phenomena encountered and on the convective heat transfer results.

Method-of-characteristic predictions of supersonic flow through conical nozzles with circular-arc-throats reveal flow conditions near the nozzle axis that would lead to shock formation. To determine if this actually occurs, pitot tube measurements were made along the axis. The ratio of pitot pressure to stagnation pressure at the nozzle inlet (Fig. 3) shows shock formation at the rather abrupt rise in pitot pressure. From the pitot tube measurements and shock wave relations the deduced oblique shock structure is seen in Fig. 3.

COOLED APPROACH DUCT

Local heat transfer and wall static pressure measurements have been obtained in a 42-in. long, 5-in. diameter cooled approach duct for the same operating conditions as the 45-15-deg nozzle data.

CONSTANT PRESSURE GRADIENT NOZZLE

The fabrication of the constant pressure gradient nozzle is completed. This nozzle will be tested after the 10-10-deg nozzle mentioned later. The constant pressure gradient nozzle with its long throat section will allow a detailed investigation of convective heat transfer and boundary layer structure in the transonic region.

TEST FACILITIES AND INSTRUMENTATION

A test was made with heated air from the JPL hypersonic wind tunnel. For convenient use of this heated air supply, it is being permanently connected into the existing unheated air supply line with valving that will allow operation of the nozzle heat transfer facility with air from either source.

An electrical resistance tubular heater with up to 40 kw power input has been installed in the water system used to cool the heat transfer apparatus. This heater provides more rapid heating of the water so the gas side wall temperature of the heat transfer apparatus is maintained above the saturation temperature of the water vapor in the heated air supply when it is turned on. This is necessary to prevent condensation on the gas side wall during start-up.

Wall static pressure taps were installed in the approach section just upstream of the nozzle for a more detailed measurement of the pressure distribution.

Hot wire probe holders have been designed and built for turbulence measurements.

MEETINGS

Dr. L. Back and Dr. R. Cuffel attended the 8th National Heat Transfer Conference August 8 – 11, 1965, in Los Angeles, California. Dr. L. Back presented a paper on "Prediction of Heat Transfer from Laminar Boundary Layers, with Emphasis on Large Free-Stream Velocity Gradients and Highly Cooled Walls," which will be published in the ASME Journal of Heat Transfer. Dr. L. Back attended a meeting of the ASME K-12 Committee on Aircraft and Astronautical Heat Transfer at the ASME Winter Annual Meeting November 7 – 11, 1965, in Chicago, Illinois. A special session on Cooling and Heating Effects on Boundary Layers for the 1966 ASME Winter Annual Meeting is being organized by Dr. L. Back, Dr. H. Wolf (University of Arkansas), and Dr. S. Gouse (Massachusetts Institute of Technology).

PLANNED ACTIVITIES FOR THE LAST HALF OF FY 1966

Pitot tube traverses off the axis of the 45-15-deg nozzle will be made to find the location of the upstream leg of the oblique shock structure along the axis. The 45-15-deg nozzle will then be removed from the system. Reports will be written on the flow phenomena and convective heat transfer in the 45-15-deg nozzle and in the cooled approach duct.

Added wall static pressure taps will be installed in the inlet region and just downstream of the throat region of the 10-10-deg nozzle. In these regions wall static pressure rises (adverse pressure gradients) were found in the 45-15-deg nozzle. To detect if shock formation also occurs in the 10-10-deg nozzle, the pitot tube traversing mechanism to be used in the 45-15-deg nozzle will be adapted. The 10-10-deg nozzle will be installed after the 45-15-deg nozzle tests are completed. The modified boundary layer probe section with six probe locations will also be installed upstream of the nozzle to study flow asymmetries.

Preliminary design of the high temperature calming section will begin.

REFERENCES

1. Back, L. H., Massier, P. F., and Cuffel, R. F., "A More Detailed Investigation of Wall Static Pressure Distributions in a Conical Nozzle With a 45-deg Half-Angle of Convergence and a 15-deg Half-Angle of Divergence," **JPL** SPS 37-34, Vol. IV, pp 143 - 148, August 31, 1965.

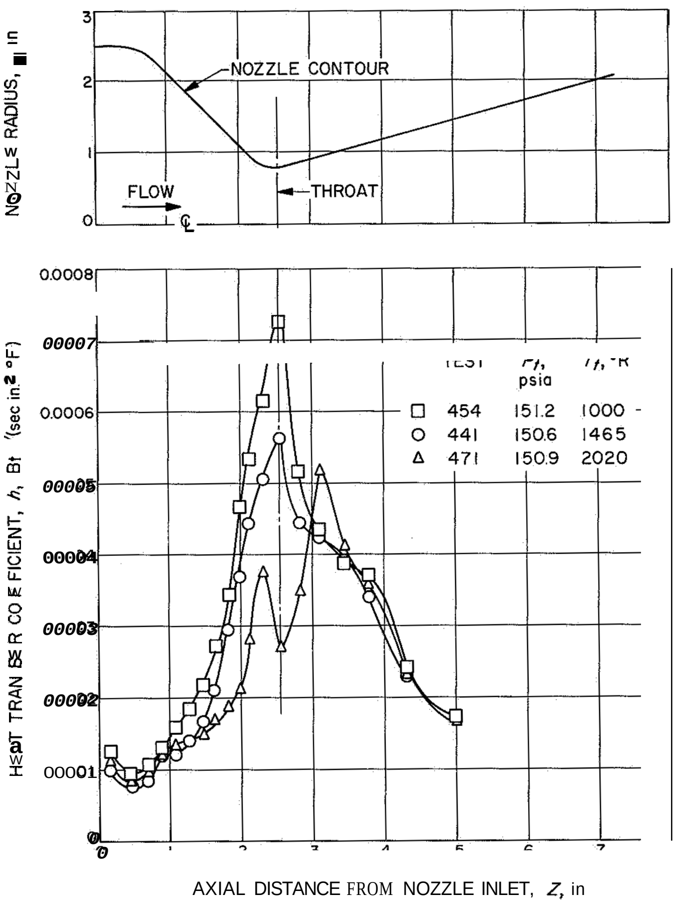

Fig. 1. Effect of stagnation temperature on heat transfer coefficient along 45-15 deg nozzle

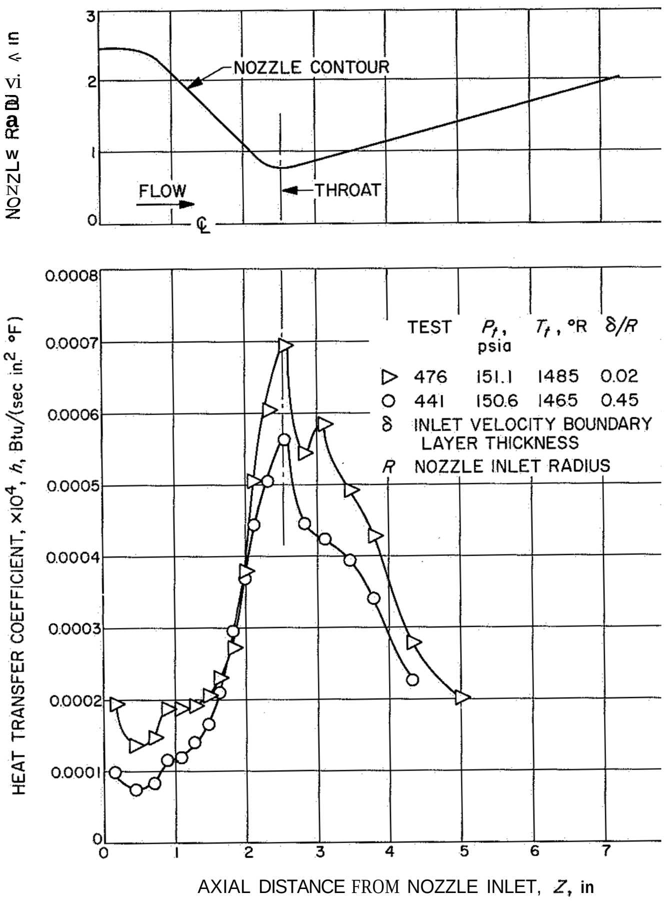

Fig. 2. Effect of inlet boundary layer thickness on heat transfer coefficient along 45-15 deg nozzle

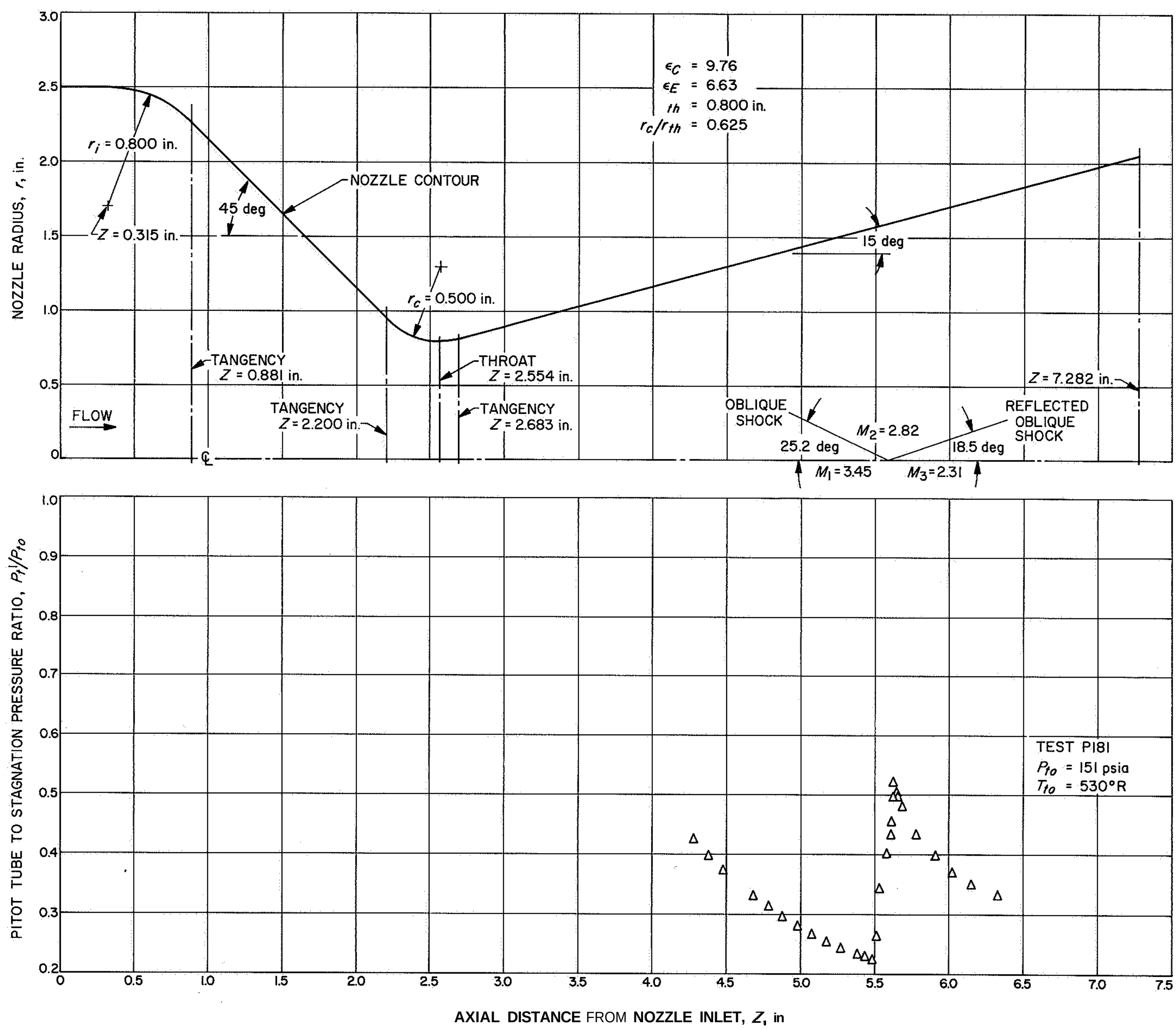

Fig. 3. Shock formation along axis of 45- 15 deg nozzle

JPL Technical Memorandum No. 33-272, Vol. II

ELECTRO PHYSICS RESEARCH (129-02)

THERMIONICS RESEARCH

NASA Work Unit 129-02-01-07-55
JPL 329-21101-1-3450
K. Shimada

OBJECTIVE

The objectives of thermionics research are twofold. The first is to gain a better understanding of the physical processes governing the operation of thermionic energy converters for the direct conversion of heat to electricity. The second objective is to make feasibility studies of schemes that would improve the performance of existing thermionic devices, or to create novel ideas for advanced thermionic devices.

Self-excited oscillations in cylindrical cesium diodes were experimentally studied to clarify the physical processes governing these oscillations. Much progress was made in understanding these oscillations. However, the use of such oscillations for the generation of ac electric power was found to be impractical.

Theories on transport effects in thermionic converters were reviewed, and a new theory is being developed based on a model with fewer constraints than others. The objective of this study is to find new schemes that would increase the output voltage of thermionic converters.

SELF-EXCITED OSCILLATIONS IN CYLINDRICAL DIODES

Cesium-filled glass diodes were built at JPL for the study of low-frequency oscillations that occurred spontaneously when the diodes were operated in the plateau region of their volt-ampere curves. During the period covered by this report, the effects of diode geometry on the frequency of these oscillations were examined. Comparisons of the frequency of oscillation were made between two diodes having cylindrical electrodes. One diode had a dylindrical collector that was 0. 5 in. in diameter and 2 in. in length. The other diode had a cylindrical collector that was 3.25 in. in diameter and 0.654 in. in length. They will be called the large diode and the small diode, respectively, in this report. The emitters were tungsten wires, 20 mil in diameter, located at the axes of the cylindrical collectors in both diodes. The results showed that the period of oscillation was linearly proportional to the product of the cesium pressure and the interelectrode gap, as shown in Figs. 1 and 2. The period of oscillation was of the same order of magnitude as the ion transit time between emitter and collector. The period of oscillation also was found to depend strongly on the cesium pressure and weakly on the potential difference across the diode. A theory is being developed to account for this behavior.

The application of an external dc magnetic field along the axis of the diode that was exhibiting the oscillations not only quenched the oscillations but also decreased the dc current through the diode. Indeed, a cyclotron cutoff accompanied by a large noise in the diode current was observed as the magnetic field reached the calculated cyclotron cutoff value. However, no magnetosonic type oscillations were observed. Therefore, the construction of metal-ceramic diodes that was planned for the study of magnetosonic type oscillations was discontinued.

TRANSPORT EFFECTS

As part of the preliminary phase of new research work on a cesium diode having a large interelectrode gap and a low cesium pressure, a theory of the transport effects for current carriers flowing through a neutral plasma was developed. The model used for the development was a one-dimensional neutral plasma for which the particle flow can be described by the following set of equations:

$$\vec{\Gamma}_+ = \mu_+ n_+ \vec{E} - D_+ \nabla n_+$$

$$\vec{\Gamma}_- = -\mu_- n_- \vec{E} - D_- \nabla n_-$$

Conditions imposed on the plasma are:

$$n_+ = n_- = n$$

$$\nabla \cdot \vec{J} = 0$$

$$\nabla \cdot \vec{E} = 0$$

The first condition provides for charge neutrality; the second provides for source-less and sink-less conditions of the net current density; and the last provides for a self-consistent electric field in the plasma. The solution for the charge density in the plasma is given by:

$$n = n_0 \exp(eV/kT_{eq}) + n_1$$

The first term is the charge density found by ambipolar diffusion of ions and electrons, and the second term is the result of drifting particle densities associated with the net electric current flow. For further details see JPL SPS 37-36, Vol. IV. In spite of its simplicity, this theory is unique in its use of: (1) the source-sink-less conditions for net current density instead of for each individual specie of current carrier, and (2) the self-consistency of the electric field in the plasma.

The analysis will be continued in other regions, such as the sheath regions of the interelectrode space of a thermionic converter, so that a theoretical volt-ampere relationship can be obtained for converters operating in an arc mode,

A Pierce type electron gun was designed and fabricated. It is to be used in heating the emitter of the diode that will be used to study transport effects. Expected beam power is about 1 kw. Preliminary testing of a similar electron gun showed a beam size of 1 cm in diameter at a distance of 6 in. from the gun, with a beam power of about 300 w.

CONSULTING WORK PERFORMED FOR THE SPACE POWER SECTION (SECTION 342)

1. Technical evaluation of research work conducted by the Thermo-Electron Engineering Co. (TEECO) on rhenium emitters, under JPL Contract 950671.

2. Discussions with Honeywell on low input voltage dc-dc converters.

3. Technical evaluation of research work conducted by TEECO, on fluorine additives and on inert gas additives, under JPL contract.

4. Technical evaluation of RCA computer program for optimization of converter performance.

PUBLICATIONS

1. Shimada, K., "Charge Transport in a Neutral Plasma Such as Exists in an Ideal Thermionic Energy Converter," JPL SPS 37-36, Vol. IV.

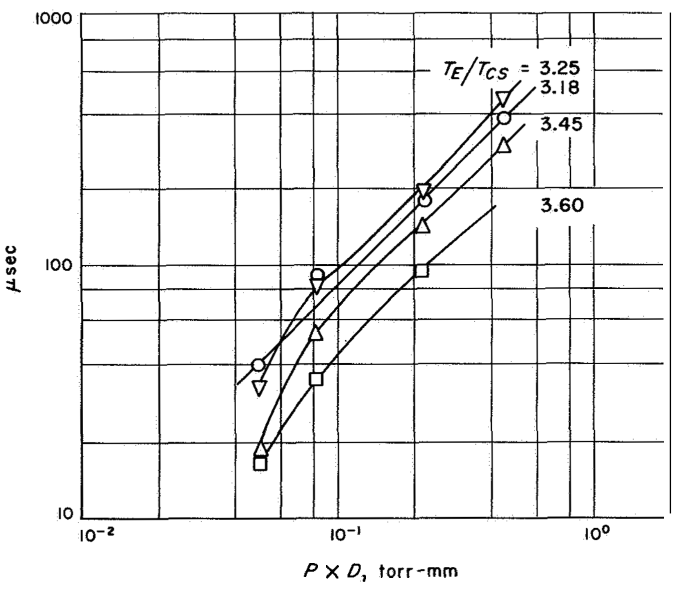

Fig. 1. Period of oscillation vs pressure x distance, large diode

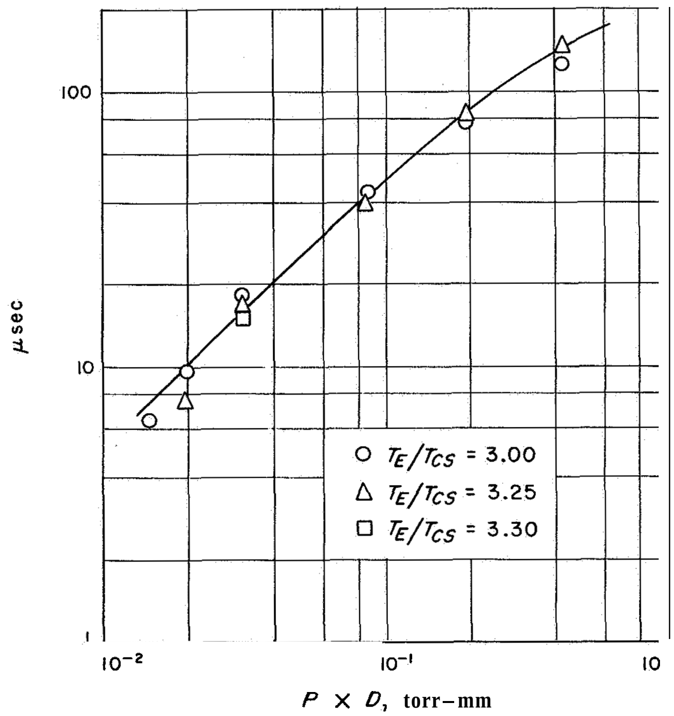

Fig. 2. Period of oscillation vs pressure x distance, small diode

PHOTOCHEMISTRY

NASA Work Unit 129-02-03-02-55
JPL 329-21001-1-3280
W. B. DeMore
O. F. Raper

OBJECTIVE

To acquire information on the chemistry of electronically excited atomic and molecular oxygen.

EXCITED ATOMIC OXYGEN STUDIES

Studies of the chemistry of electronically excited atomic oxygen have continued as the primary activity in the Photochemistry project. Topics emphasized during the reporting period have been chemical mechanisms for the electronic deactivation of $O(^1D)$ and mechanisms for the reaction of $O(^1D)$ with hydrogen-containing compounds. Also, new investigations on reactions of electronically excited molecular oxygen have been carried out.

Experimental work in the area of chemical deactivation has been directed toward finding the relative efficiencies of species such as nitrogen, oxygen, and argon as deactivators of $O(^1D)$ in processes involving two-body collisions. The latter information is of particular importance to upper atmosphere chemistry. The experimental approach involves ultraviolet photolysis of ozone in the presence of added deactivator at pressures in the range of 25 to 100 atm. The observed quantum yields of ozone photodissociation as a function of pressure may be correlated in a straightforward manner with the pressure dependence for the rate of removal of $O(^1D)$ by the added deactivator. Data obtained to date, although quite tentative and subject to added verification, suggest that O_2 is not an efficient deactivator of $O(^1D)$ in two-body processes. These results, coupled with earlier work from JPL, point out with increasing certainty that $O(^1D)$ in the upper atmosphere is primarily removed through collisional deactivation with N_2 rather than with O_2 as has often been assumed.

Experimental results on the reaction of $O(^1D)$ with methane have been analyzed and these reveal that the initial reaction involves three paths: a direct insertion of $O(^1D)$ into the C-H bond of CH_4 to give CH_3OH, a molecular path giving CH_2O and H_2, and a radical path giving CH3 and OH. The reaction is found to have zero activation energy and to be quite rapid, proceeding at a rate 0.3 times as fast as the reaction of $O(^1D)$ with O_3. From the scavenging effect of added O_2 in these experiments, the first quantitative rate data on the reaction of CH3 with O_3 has been obtained. The oxidation of CH3 by O_3 is found to have zero activation energy and to occur at a rate equal to the reaction of CH3 with O_2.

Apparatus has been designed and assembled for study of the reaction of $O(^1D)$ with H_2 dissolved in liquid Ar at 87°K. Features of this equipment that distinguish it from earlier apparatus are all-metal construction, a variable cell path length, and capacity for high-pressure operation. Besides information on the initial $O(^1D)$-H_2 reaction, these experiments are expected to yield rate data on the reactions of both H and OH radicals with O_3, and also to provide a convenient means for studying the reactions of these radicals with other species under well-defined conditions.

As a continuation of the foregoing studies, experiments on the reaction of $O(^1D)$ with other H-containing compounds, such as ethane, propane, and ethylene are planned to see if a correlation exists between structure of the substrate molecule and the mode of the initial reaction (i.e., the relative rates of the insertion and fission reaction paths).

EXCITED MOLECULAR OXYGEN STUDIES

Studies of the chemistry of electronically excited molecular O_2 are continuing both in the gas phase and in the liquid phase at low temperature. Excited O_2 is produced by absorption of monochromatic radiation (2537Å) in the Herzberg bands and the reactive species is believed to be $O_2(^3\Sigma^+_u)$. The reaction $O_2^* + O_2 \rightarrow O_3$ t O occurs with a quantum yield of 0. 01 in the gas phase at 25" C but cannot be detected in liquid O_2 at 77°K. Further experiments are planned to see if the reaction rate has a temperature dependence that can be satisfactorily expressed as an Arrhenius activation energy.

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PLASMA PHYSICS RESEARCH
NASA Work Unit 129-02-03-03-55
JPL 329-20701-1-3270
A. Bratenahl

OBJECTIVE

The objective of this work is the understanding of the mechanics of the "relinking of lines of force" at a neutral point in a highly conducting medium.

AN EXPERIMENTAL STUDY OF A NEUTRAL POINT IN A PLASMA

Experimental Progress

No new measurements have been obtained in the reporting period because the equipment has had to be moved from the old location to the new building. The time made available by the move has been used to improve the electronic control of the device and also to increase the amount of energy storage in the capacitor bank. The equipment has been reassembled and should be operational in January.

The analysis of the experiment shows that density is an important variable. Therefore, the decision has been made to obtain and use an laser-Schlieren system to obtain the density field in the device. A set-up similar to the one used by R. H. Lovberg for studying a θ pinch is contemplated.

Theoretical Results

The current status of our understanding the neutral point problem was presented at the A. P.S. Plasma Physics Division meeting in San Francisco in November. The new aspects of the theoretical model lead to the following conclusion.

In essence, the solution for very rapid flux reconnection in the presence of very high conductivity depends on the following conditions:

1. Before the process begins, the mean magnetic energy density must be much greater than the mean gas (plasma) energy density.

2. All current sources of the magnetic field must be at a finite distance, which means that the "infinite geometrics" often used in the past for analytical convenience will not work; in fact, they introduce a kind of degeneracy.

3. The more compressible the gas, the faster the process can take place. This is particularly interesting because the chromosphere and lower corona, where flares take place, can be compressed even more readily than isothermal compression on account of radiative heat losses. It has, in fact, been said that it is unstable in this respect.

Under the above conditions, it turns out that the electric field that sets the rate of flux relinking does not depend directly on the resistivity of the medium, but rather on the resistive voltage drop in a finite circuit path whose cross-sectional area is rapidly reduced to an arbitrarily small size by dynamic motions driven by large Lorentz forces.

Further progress of this work will be reported at the AIAA Plasmadynamics Conference, March 2 – 4, 1966, at Monterey, California.

QUANTUM CHEMISTRY
NASA Work Unit 129-02-03-04-55
JPL 329-20801-1-3280
M. Geller

)BJECTIVE

The objective of this work unit is to develop and test various methods for ccurate calculation of the wave functions and energies of small atoms and molecules. 'his involves analysis of electron correlation effects by the use of many- onfiguration elliptical bases for diatomic molecules and by the use of Sinanoglu's >any-electron approach. Also of continuing interest are techniques for the infinite onfiguration interaction approach to atoms and molecules and, finally, the analysis f upper and lower bounds and the convergence properties of trial wave functions to ssess their goodness.

ORRELATION ENERGY

The ab-initio calculation of the Be atom by the Sinanoglu many-electron ıeory has been completed and published (Ref. 1), and 98% of the correlation energy ɜs been accounted for. The calculations for the first row series isoelectronic to e (B^+, C^{++}, N^{+++}, F^{+5}) have been completed and results are being analyzed and ritten up for publication.

Two-center, two-electron coulomb integrals have been evaluated by the ourier Convolution method. A paper has recently been written discussing the omic integrals needed for zero-field splitting calculations.

ESONANT ELASTIC SCATTERING

A theory proposed to calculate the energies and wave functions of negative-ion ɜsonant elastic scattering states, and a successful test of the theory for elastic :attering of electrons by H_2, has been published (Ref. 2). The theory is based on e development of an approximate variation principle. Further verification is in ·ocess.

ƖPROVED HARTREE-FOCK WAVE FUNCTIONS FOR H_2O

Improved Hartree-Fock wave functions, approximated as a linear combination Slater-type orbitals (LCSTO), have been calculated for the water molecule. A inimal basis set of 8 STO's and a maximum of 20 have been investigated. Both nes the screening parameters of the STO's have been systematically varied to ınimize the energy further.

The ground-state energy obtained with the maximum basis set is better than y reported earlier, but the dependence of energy on the HOH angle is less tisfactory. The minimum is at about 4 deg greater than the observed 105 deg. is may well be due to the "unbalance" of introducing $2p\pi$ orbitals on the hydrogens thout being able to add d orbitals to the oxygen with our present programs. The sults are being analyzed and written up for publication (Ref. 3).

M. Geller left JPL in October, and this work is being carried on by consultants until he is replaced.

REFERENCES

1. Geller, Murray, Taylor, Howard S., and Levine, Howard B., "Many-Electron-Theory <u>ab Initio</u> Calculation for the Be Atom," <u>J. Chem. Phys</u>., Vol. 43, p. 172 (1965).

2. Taylor, Howard S. and Williams, J. K., "Proposed Theory of Calculating the Energy of Negative-Ion Resonant Elastic Scattering States and of the Pre-Ionization States of Electronic Spectroscopy," <u>J. Chem. Phys</u>., Vol. 42, p. 4063 (1965).

3. Merrifield, Donald and Pitzer, Russell, "Improved Hartree-Fock Wave Function for H_2O," (to be published).

RADIATION CHEMISTRY

NASA Work Unit 129-02-03-06-55
JPL 329-21301-1-3280

J. King, Jr.

OBJECTIVE

The objective of this work unit is to study the radiation chemistry of gases for obtaining information on the effects of ionizing radiation on planetary atmospheres. Also, to continue the study of the nature of gas-solid interactions to understand more of the nature of radiation damage in solids.

GAS-SOLID INTERACTION

The main activity during this reporting period has been the application of the new electrostatic theory of physical adsorption to some gas sorption systems. The electrostatic theory was developed to explain the low temperature separation of the hydrogen isotopes on an alumina column. It was necessary to separate the isotopes during an investigation of the radiation chemistry of hydrogen.

The electrostatic theory differs from other theories of physical adsorption because there is no direct interaction between the adsorbed molecules and the ions of the adsorbent. Instead, in the electrostatic concept, the adsorbed molecules interact directly with the surface electric field of the adsorbent. Because of the type of interaction, the polarization of the adsorbent constituents by the adsorbed gas does not occur, and forces that involve such polarization effects are not applicable. London dispersion forces, which were earlier thought to predominate in all physical adsorption systems, are excluded. The theory has wide application in the field of surface catalysis and other surface phenomena such as corrosion. The theory also makes possible for the first time a very sensitive measure of the effects of radiation damage on the surface of solid;. Using the chromatographic technique, the gaseous adsorption on an irradiated and unirradiated solid gives a direct observation of the alteration of surfaces, especially their electric fields, by ionizing radiation.

The electrostatic theory has been successfully used to explain some of the experimental observations in adsorption chromatography. It is able to predict the order of elution of gases from many columns. For methane and the rare gases on an Al_2O_3 column, the gases (as predicted by the theory) elute from the column by their relative polarizabilities. That methane behaves like a rare gas is consistent with the concepts of the electrostatic theory because its polarizability is isotropic.

The electrostatic theory was also used to explain why the retention times of the isotropic methanes on a charcoal column decreased in accordance with the decrease in the polarizabilities as deuterium or tritium was substituted for the hydrogen in methane.

Perhaps the most striking application of the electrostatic theory has been to the adsorption of gases on molecular sieves. The prevailing belief had been that the adsorption and separation of gases on molecular sieves were governed by the sizes of the "holes" or "channels" in the molecular-sieve structure. However, because the symmetrical chromatographic peaks are obtained with molecular sieve columns tends to repudiate this hypothesis. If molecules must diffuse through 4 to 13 Å diameter holes or channels, then one would expect to see much tailing in the peaks. The absence of tailing suggests that the process is not diffusion controlled and that adsorption on molecular sieve columns is similar to adsorption on other columns. To support this contention, a detailed analysis was made of the separation of H_2, N_2, O_2, CH_4, and isobutane on a Linde 5A molecular sieve column. The results showed that the heats of adsorption of the gases on the sieve were essentially the same as the heats on other adsorbents and were much larger than the heats of liquefaction. Added support is because the heat of adsorption of NH_3 on Linde sieve X is a function of the substituted cation in the sieve; the heat value increasing as the polarizing power of the cation increases. This is the expected behavior if electrostatic interactions are responsible for the adsorption and separation.

The most unique application of the theory and the one that has stirred the most interest has been in the field of anesthesiology. The electrostatic theory has been used to explain the anesthetic potency of many gases, including xenon, whose anesthetic properties are difficult to interpret because it is chemically inert. Of the theories that had earlier attempted to explain the mechanism of gaseous anesthesia, the hydrate theories of Pauling and Miller were the best known and most widely accepted. However, both theories suffered from the same serious drawback because they did not include the gases that were obvious anesthetics but did not form hydrates. These gases were not excluded in the electrostatic approach in which the gases were assumed to interact directly with some charged sites on the nonaqueous phase of the encephalonic fluid. This interaction was shown to be a function of two of the properties that are possessed by all gases, size and polarizability. Therefore, in applying the electrostatic theory to gaseous anesthesia, the anesthetic properties of all the gases are explained without invoking "hydrate" or other aggregate formations.

FUTURE INVESTIGATIONS

The application of the electrostatic theory to other sorption systems shall continue. All the earlier systems have involved, in some way, oxide surfaces. Future applications will treat nonoxide surfaces such as CaF_2, $BaCl_2$, etc., to find out if the electrostatic theory is applicable to these systems.

During the reporting period, the radiation chemistry facility was relocated in a new building, which necessitated a period of inactivity in the experimental program. However, the photolysis of nitrogen dioxide in a nitrogen atmosphere was completed and a manuscript is being prepared for publication.

PUBLICATIONS AND PRESENTATIONS DURING THE PERIOD

1. King, James, Jr., and Benson, Sidney W. "The Adsorption and Separation of Gases on Molecular Sieve," JPL SPS 37-34, Vol. IV, July 1965.

2. King, James, Jr., "The Quantum Yield at 3660 Å for Trace Quantities of Nitrogen Dioxide," JPL SPS 37-34, Vol. IV, July 1965.

3. King, James, Jr., and Benson, Sidney W., "An Electrostatic Theory of Gaseous Anesthesia," JPL SPS 37-36, Vol. IV, December 1965.

4. King, James, Jr., and Benson, Sidney W., "Electrostatic Aspects of Physical Adsorption with Some Applications for Molecular Sieves and General Anesthesia," (accepted for publication by Science Magazine).

5. King, James, Jr., and Benson, Sidney W., "Electrostatic Interactions in Gas Solid Chromatography," (accepted for publication by Analytical Chemistry and presented at the Third International Symposium on Advances in Gas Chromatography, Houston, Texas on October 18, 1965).

NUCLEAR PHYSICS RESEARCH
NASA Work Unit 129-02-03-08-55
JPL 329-21701-1-3280

A. B. Whitehead

OBJECTIVE

The objective of this work unit is to conduct experimental research in selected problems of nuclear physics and the physics of heavy-ion interaction with matter. Problems are selected for their intrinsic physical interest, for the particular applicability of the results to technology important to NASA, and for their challenge to the unique capabilities of the present personnel and apparatus. The goal of current experiments concerns: (1) the specific energy loss of fission fragments in various stopping media, (2) the yield and energy spectrum of secondary electrons accompanying fission, and (3) current topics in fission physics.

APPARATUS

The Dynamitron positive ion accelerator has yet to achieve an acceptable level of operation. The contractor supplied a newly designed ion source that has improved the geometrical properties of the beam spot on target, although it has yet to improve the maximum obtainable current. Deterioration of the filament coating material has been a recurring problem with the ion source.

The multiparameter data acquisition system on lease from Nuclear Data, Inc. was installed and is functioning well. The system converts analog pulses from up to four nuclear detectors into digital form, records the information on computer compatible magnetic tape, and provides on-line monitoring in the 4096 word memory.

A purchase order for an accelerator beam analyzing system, consisting of a 90 deg analyzing magnet and quadrupole lens was awarded to Magnion, Inc. Delivery is being postponed until September because of a delay in moving the Dynamitron to its permanent location.

MEASUREMENT OF SECONDARY ELECTRONS GENERATED BY FISSION FRAGMENTS

A simple lens experiment has been performed to measure the numerical distribution of secondary electrons generated by a fission fragment passing through a thin nickel foil. Secondary electron generation is intimately connected with the stopping process and should give added information about the physical phenomena involved. Also, a more thorough understanding of secondary electron generation will be useful where suppression or enhancement of the process is desired.

The results of this experiment were presented at the 12th Nuclear Science Symposium, IEEE, and will be published in the proceedings of that conference. The basic results of the experiment are:

1. The usefulness of the lens technique is demonstrated.

2. A curve is given that is interpreted as the probability of a given number of secondary electrons being emitted when a fission fragment traverses a thin nickel foil.

3. The response of a gold silicon surface barrier detector to very low energy electrons is measured. The detector shows a pulse height defect that may be attributed to the energy loss by the electron in passing through the surface gold layer.

4. Using a suitably biased grid and observing the median of the number of electrons emitted per fragment, a curve has been obtained that gives some indication of the energy spectrum of the secondary electrons. This integral bias curve has been fitted to a simple power law $N(V) = N_1 V^{-0.29}$. To obtain a differential energy spectrum, it is necessary to make some assumption about the angular distribution of these electrons. If the distribution is isotropic, or if the angular distribution is not energy dependent, then it may be shown that the differential spectrum is given by the relation $n(\epsilon) = \text{const } \epsilon^{-1.29}$. This does not fit a Maxwell-Boltzmann distribution; therefore suggesting that the process is not one of thermal equilibrium and evaporation in a small volume of the foil (thermal spike model). An analysis of the distribution as reflecting the coulomb scattering of these electrons becomes complicated by the strong angular dependence of this process.

Further experimental work is in progress using the lens technique. Data is being accumulated using the multi-parameter data acquisition system so that the numerical distribution of secondary electrons may be correlated with the mass, energy, or velocity of the fragment. A number of thicknesses and materials are to be used. Preliminary examination of the data shows that for the case of nickel, the distribution is independent of the fragment energy; but for a formvar foil, the dependence or energy is quite striking.

Besides the lens experiment, an electrostatic spectrometer has been constructed to measure the energy spectrum more accurately. The spectrometer is in the initial stages of testing and the first results are expected in the Spring.

EFFECTS OF ATOMIC SCATTERING ON THE PERFORMANCE OF SOLID-STATE DETECTORS

Solid-state detectors show a large pulse-height defect and energy dispersion when detecting heavy ions. The contribution of the atomic scattering process to this defect and dispersion has been computed. The secondary process of a recoiling detector atom causing further electron-hole pair formation was included in the treatment. Final results of this work will appear shortly in Reviews of Scientific Instruments.

The computation assumed that the detector was randomly oriented. A comparison of these results with data available in the literature shows good agreement for the pulse-height defect, showing that atomic scattering accounts for most of the defect over a wide range of Z and energy. Data for detector resolution are available over a limited portion of the computed curve and suggest that some process besides atomic scattering is contributing to the dispersion.

These results were discussed informally at a seminar at Oak Ridge National Laboratory in August. Partly as a result of this work, the ORNL experimental team undertook to measure the defect and dispersion for heavy ions directed along a crystal axis where atomic scattering should be minimized. Their results show that the defect drops to zero and the dispersion is diminished by a factor of at least two under these conditions, supporting the predictions of our work.

PUBLICATIONS

1. Haines, Eldon L. and Whitehead, A. Bruce, "Pulse-Height Defect and Energy Resolution in Semiconductor Detectors," to be published in Reviews of Scientific Instruments.

2. Whitehead, A. Bruce, "Yield and Energy Spectrum of Secondary Electrons Generated by Fission Fragments," to be published in the Proceedings of the 12th Nuclear Science Symposium, IEEE.

OPTICAL PHYSICS RESEARCH

NASA Work Unit 129-02-05-01-55
JPL 329-20101-1-3450

A. R. Johnston
M. S. Shumate
R. Ueda

OBJECTIVE

The objectives of this work unit are to conduct research on the interaction of light with matter, which will lead to a better understanding of the basic operation of optical sensors, and demonstrate the feasibility of new optical devices. Three immediate objectives are: (1) to obtain a better understanding of the electro-optic effect in ferroelectric crystals relevant to its application in light modulators, (2) to obtain a better understanding of magneto-optic effects relevant to their application in "reading" and "writing" of magnetically stored information, and (3) to obtain a better understanding of the photoconductive effect in thin films relevant to its application in light detectors.

ELECTRO-OPTIC EFFECT

The experimental part of the investigation of the electro-optic effect in single crystal barium titanate has been completed and reported on during the last reporting period. Measurement of the transient electro-optic response to an applied field pulse, which closely approached a condition of zero induced strain, was completed. These results are presented in the October issue of Applied Physics Letters (Ref, 1). Together with the low-frequency results published earlier (Ref. 2), these data form a complete experimental picture of the effect in $BaTiO_3$, for the field applied in either principal direction, and including the effect of strain. These results were obtained at 5461 Å using flux-grown $BaTiO_3$ single crystals only, and good sample-to-sample agreement was obtained. The main conclusions drawn to date are:

1. The strain contribution to the low-frequency effect is very large: 4/5 of the total for an [001] field, 1/2 of the total for a [100] field at room temperature. The use of $BaTiO_3$ as an optical modulator at microwave (or radio) frequencies must take this into account.

2. A similar strain contribution (60%) occurs in the quadratic effect seen in the cubic state above the Curie temperature.

3. The response per unit-induced polarization, $x_{ij} = r_{ij}/(\epsilon_{jj}-\epsilon_0)$, is similar in magnitude to other materials, and is relatively constant with temperature. The range observed in tetragonal $BaTiO_3$ was 0.075 to 0.025 m^2/C, compared to 0.058 m^2/C in KDP.

4. The half-wave voltage for a low-frequency [001] field at room temperature is very low, approximately 400 v. Half-wave retardation can be achieved with a voltage of the same order in the cubic state, within a few degrees of the transition.

Some observations are now being made of the Kerr effect in $BaTiO_3$ grown by ι method of Linz (Ref. 3), because a low-frequency Kerr constant 40% higher than ours was reported by Geusic (Ref. 4) on Linz material. The Kerr constant of the Linz material seems to be about 10% higher than the flux-grown crystals, according to these observations. This is supported by another measurement by C. J. Johnson (Ref. 3), which was also about 10% higher, but was made at a different wave-length (6328 Å).

A paper was prepared (Ref. 5) for presentation at a symposium sponsored by the Avionics Committee of NATO, and copies are available from the author. Besides reviewing these results for $BaTiO_3$, the paper described the nature of several types of electro-optical modulators. A rather detailed bibliography of the literature on electro-optic materials and devices was included. The data available from the literature on all other electro-optic materials was summarized and compared to try to show similarities within several families of crystals.

A preliminary report has also been prepared describing the instrumental technique used to obtain the strain-free results. A paper on this subject is planned for future publication in Applied Optics,

Samples of CuCl are now being oriented and prepared for study. A very preliminary observation of the low-frequency response of one sample of $NaNO_2$ shows that it exhibits a value for x_{ij}, the response per unit polarization, which is normal. $NaNO_2$, like $BaTiO_3$, is a ferroelectric, with a large temperature variation of dielectric constant,

REFERENCES

1. Johnston, A. R., Appl. Phys. Lett., Vol. 7, p. 195 (1965).

2. Johnston, A. R., and Weingart, J. M., J. Opt. Soc. Am., Vol. 55, p. 828 (1965).

3. Johnson, C. J., Appl. Phys. Lett., Vol. 7, p. 221 (1965).

4. Geusic, J. E., et al., Appl. Phys. Lett., Vol. 4, p. 141 (1964).

5. Johnston, A. R., "Electro-Optic Crystals and Their Use for Light Modulation," presented at the Symposium on Opto-Electronic Components and Devices, AGARD, Paris, September 6 – 9, 1965.

MAGNETO-OPTIC EFFECT

A new research effort was started during this reporting period. This work is being done by M. S. Shumate, who has completed his work on optical second order polarization coefficients. This new work is concerned with magneto-optic effects (such as the Faraday effect, the Cotton-Mouton effect, and the Kerr magneto-optic effect), and it is hoped that the work will lead to the demonstration of the feasibility of an optical read-write device capable of use with a micro-particle high-density magnetic memory. The memory elements are small needle-shaped particles ($0.5\,\mu \times 0.05\,\mu$) of γ-Fe_2O_3 and are oriented in an array with a particle density that could be as high as 10^8 particles/cm^2. Each particle would serve as an individual binary memory element, with the ability to read/write into each particle depending on magneto-optic interactions.

There is a fundamental difficulty that must be overcome for such a read/write device to be made feasible: the interaction volume is small (on the order of 1000 Å in diameter and 10,000 Å long), and a material that shows a very strong magneto-optic interaction must be used. Of the two magneto-optic effects, Faraday and Cotton-Mouton, the Faraday effect is usually larger by several orders of magnitude.

Major emphasis during the next 6 mo will be placed on a theoretical and experimental study of the Faraday effect in solids. The first materials to be considered will be ferro-magnetic and para-magnetic materials, because they are known to show large Faraday effects in thin layers. This work is being done in close cooperation with the magnetics research task in the same section at JPL.

STRUCTURE AND PHOTOCONDUCTIVE PROPERTIES OF EVAPORATED CADMIUM SULFIDE FILMS

This research is to find the relationship between the structural and photoconductive properties of CdS thin films, aiming toward the improvement of the characteristics of photoconductive cells. Preliminary evaporations made during this report period showed that thin films of CdS vary in color, depending on the substrate temperature. If the substrate temperature is lower, they are black. At higher substrate temperatures, they vary from green to yellow. These changes in color are related to sulfur vacancies in the crystal lattice. Analysis of x-ray powder diagrams of these CdS thin films, whichwere evaporated onto glass substrates, showed that the diffraction patterns are somewhat different between black and yellow samples. The x-ray examination revealed that diffraction peaks in the black samples were double, merging into single peaks for the yellow samples.

An x-ray fluorescence analysis of CdS thin films evaporated under various conditions showed no measurable difference in the cadmium to sulphur ratio. This experiment will be repeated in the future with different film thickness and impurity contents.

The evaporation rate of CdS, from a modified Knudsen cell used as an evaporator, was found with a microbalance using a sensitive quartz oscillator. The sensitivity of this instrument is estimated to be within 0. 1 Å in thickness. Measurable evaporation begins at a temperature of about 300" C and increases rapidly above about 600°C as shown in Fig. 1.

A combination of evaporator temperature, substrate temperature, and film thickness that yields best behavior as a photoconductor will be sought. The earlier measured evaporation rate as a function of temperature will be used to find film thickness, because reliable operation of the microbalance on a routine basis is difficult to achieve. The properties listed in the last reporting period will be measured for these films. It is desired to develop an understanding of the observed correlations that is adequate to form a basis for improving the characteristics of practical evaporated CdS photodetectors'; in particular, for avoiding an increase in resistance to awkwardly high levels after sterilization and for decreasing aging processes that cause continuous resistance drift.

OPTICAL SECOND-ORDER POLARIZATION COEFFICIENTS

The finding of the second-order polarization coefficients of barium titanate has been completed and is reported in JPL SPS 37-35, Vol. IV. The results for two of the coefficients, d_{15} and d_{33}, are consistent with current theories; that is, the magnitude of the coefficients increased with decreasing wavelength. However, the magnitude of the coefficient d31 decreased with decreasing wavelength. This is not now understood, and should be investigated further, The finding of the coefficients as a function of temperature will not be completed because of a lack of consistent data. There are indications that the barium titanate crystals used depoled slightly at high temperature when heated by the energy absorbed from the optical maser beam. No further work is planned on this project.

PUBLICATIONS AND PAPERS PRESENTED

1. Johnston, A. R., and Weingart, J. M., "Determination of the Low-Frequency Linear Electro-optic Effect in Tetragonal $BaTiO_3$," J. Opt. Soc. Am., Vol. 55, No. 7, p. 828-834 (1965).

2. Johnston, A. R., "The Strain-Free Electro-optic Effect in Single-Crystal Barium Titanate," Appl. Phys. Lett., Vol. 7, p. 195-198 (1965).

3. Johnston, A. R., "The Electro-optic Effect in $BaTiO_3$," JPL SPS 37-36, Vol. IV

4. Johnston, A. R., "Technique for Observing the Electro-optic Effect at Constant Strain," J. Opt. Soc. Am., Vol. 55, p. 1580 (1965), abstract only.

5. Johnston, A. R., "Electro-Optic Crystals and Their Use for Light Modulation," presented at the Symposium on Opto-Electronic Components and Devices, AGARD, Paris, Sept. 6 – 9, 1965.

6. Shumate, M. S., "Interferometric Measurement of Large Indices of Refraction," Appl. Optics, (to be published in February 1966).

7. Shumate, M. S., "Measurement of Optical Second Order Polarization Coefficients in $BaTiO_3$ by Reflection," J. Opt. Soc. Am., Vol. 55, p. 1575 (1965), abstract only.

8. Shumate, M. S., "Measurement of the Second-Harmonic Generation Coefficients in Barium Titanate," JPL SPS 37-35, Vol. IV.

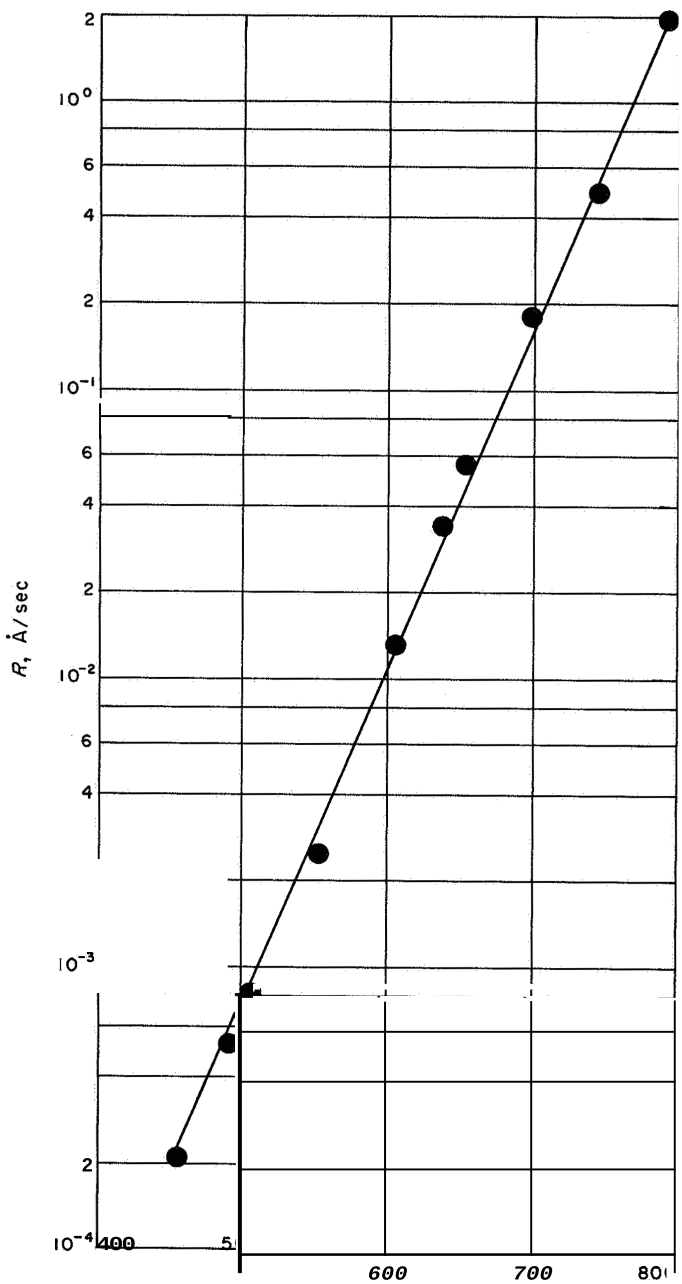


Fig. 1. Evaporation rate of cadmium sulfide

CRYOGENICS RESEARCH

NASA Work Unit 129-02-05-02-55
JPL 329-20201-1-3450

W. M. Whitney
N. Sirri

OBJECTIVE

Many of the equilibrium properties of liquid helium below its lambda point at 2.2°K can be successfully related to a specific microscopic model in which it is assumed that the thermal energy resides in two types of localized excitations: phonons, which are quantized density fluctuations or sound waves; and rotons, which are correlated motions of a few helium atoms over regions several angstroms in extent. It is the nonequilibrium rather than the equilibrium behavior that provides the more severe test of a theory, however, and there is indication from several experiments that the transport properties of liquid helium below 0.8°K have not been properly accounted for. The immediate objective of our research is to provide experimental information that will contribute to the development of an improved model for dissipative processes. The long-range goal of this and related work is to advance our understanding of the behavior of matter in the condensed state. Models similar to the phonon-roton model for liquid helium, although with different energy carriers involved, are used in the description of the properties of many other materials — semiconductors (electrons and holes), metals (plasmons and quasi-particles), molecular crystals (excitons), and ferromagnetic materials (magnons) to give a few of many examples; and similar mathematical techniques and physical ideas are used in the elaboration of these properties.

The objective of the concluding work on the cryogenic gyroscope is to measure and separate out the three main sources of drift that exist in our cryogenic gyroscope.

VELOCITY AND ABSORPTION OF SOUND IN LIQUID HELIUM

Our present efforts are divided between two parallel activities: (1) we are studying information from past experiments that has not been fully exploited to obtain a better definition of areas of agreement and disagreement with existing theory, and (2) we are measuring the absorption and velocity of sound at frequencies in the range 10 – 100 Mc.

A major portion of our time during the reporting period has been spent in the analysis of data acquired in experiments carried out with C. E. Chase (National Magnet Laboratory, M.I.T.), to measure the velocity of sound in liquid helium at 1.00, 3.91, and 11.9 Mc. It was found in these experiments that the velocity goes through a maximum near 0.7°K, and exhibits dispersion over a temperature region of about 1/2 deg centered roughly on the maximum. By subtracting smoothed values of the measured velocity at 1 Mc from those at 4 and 12 Mc and plotting them against temperature, we obtain the curves shown as solid lines in Fig. 1. These numbers are compared with similar ones derived from a theory of sound propagation developed by Khalatnikov from the phonon-roton model. Khalatnikov does not explicitly find the velocity, but an expression for it can be extracted from his equation for the complex wave velocity. After lengthy numerical analysis, we obtain the curves shown as dotted lines in Fig, 1. The observed and measured dispersion over the frequency interval 4 – 12 Mc are comparable in the neighborhood of the peak and above, although the two sets of curves seem to be displaced relative to one another by about 0.05°K. At low temperatures, the observed dispersion over the range 4 – 12 Mc is far greater than that predicted by the theory. (Note that the 4- and 12-Mc curves merge below 0.75°K.) This discrepancy is a large one and supports the conclusion, earlier based on attenuation measurements alone, that existing theories of sound propagation in liquid helium are inadequate at temperatures below 0.7 – 0.8°K. A more complete description of the work summarized above will appear in the forthcoming issue of the JPL SPS 37-36, Vol. IV. A paper that gives an account of the experiment and our present conclusions was to have been submitted to Physical Review before the end of this year, but the writing has required more time than anticipated and several weeks' work still remains. An analytical paper is being prepared in which the temperature dependence of the velocity of sound at zero frequency over the temperature interval 0 – 1.8°K is calculated. This paper is also being written in collaboration with Chase, and may be submitted as a companion paper to the first one.

During the period before John Harding left, experimental work with the ^3He cryostat was suspended so that full-time technical support could be given the concluding phases of the cryogenic gyroscope project. Our electronics technician left in September and a suitable replacement has not yet been found. For these reasons, work in the laboratory has proceeded less rapidly than had been projected; nevertheless, some progress has been made. Two phase detectors have been put into operation to enable accurate velocity measurements to be made at 10 Mc and some of the 30 Mc gear has been assembled. The apparatus that will be used at 90 or 110 Mc will be built when technician help is again available. Earlier tests of the ^3He cryostat had revealed the presence of heat leaks, into the working space containing the sound apparatus, that were much larger than had been expected. A major source of the heating has now been identified, and the time during which the working space stays cold after one ^3He condensation has been increased by a factor of four. With the heat input so reduced, it has been possible to find out that the pumping tube leading from the ^3He pot in the cryostat is too small, and eventually we will have to enlarge it to achieve temperatures much below 0.5°K; however, as it now operates, the system is satisfactory for much of our work. The cryostat and its operation will be described in a future JPL SPS.

Motivated by certain analogies between the properties of very viscous liquids and those of liquid helium at low enough temperatures, we have carried out a search for shear waves in liquid helium at 10 Mc and 0.5°K. The results have so far been negative. According to current theories of liquid helium, we should not expect to see such waves at any frequency. But because these theories have fallen short in accounting for other characteristics of sound propagation at these temperatures, we believe that an exploratory study like we are making has enough justification from an experimental standpoint alone; and we shall repeat the measurements systematically as we develop the capability to work at higher frequencies and lower temperatures, where the probability of seeing an effect is greater.

CRYOGENIC GYROSCOPE

During this reporting period a review of the cryogenic gyroscope work was held for the Manager of the Guidance and Control Division, section managers, and others in the Guidance and Control Division concerned with inertial-guidance techniques. The conclusions summarized during this review were:

1. The research phase of the cryogenic gyroscope program has shown that the cryogenic gyroscope is feasible, and has also contributed several ideas that would be useful in an operational cryogenic gyroscope.

2. Although the feasibility of the cryogenic gyroscope has been shown, the start of a development effort by JPL on the cryogenic gyroscope is not appropriate. Mainly because the electrostatic gyroscope is much closer to meeting JPL requirements for this type of instrument. The electrostatic gyroscope and the cryogenic gyroscope are similar in concept and expected performance, and work was started on both types of instruments about 8 yr ago. Since then, a great deal more money has been spent on the electrostatic gyroscope (ESG) and operational units of the ESG have been built. The expenditure of similar amounts of money (about $5 million) for a development effort on the cryogenic gyroscope is not warranted now that the electrostatic gyroscope is available,

3. Except for a few activities to complete experiments in progress, work on the cryogenic gyroscope at JPL is to be discontinued. (This occurred on October 1, 1965, when Dr. Harding, the principal scientist for this task, stopped working on the cryogenic gyroscope.)

A comprehensive final report covering the entire cryogenic gyroscope research effort at JPL is now being prepared. Certain experimental work on the cryogenic gyroscope is being completed by Donald Lawson, the Engineering Assistant who had worked for Dr. Harding. This work includes the fabrication of a readout system and the use of this readout system to obtain drift data that will make possible the measurement and separation of the three main sources of drift in the cryogenic gyroscope. These three sources of drift are: (1) mass unbalance, (2) trapped flux, and (3) the London moment. These sources of drift will only be identified and measured; no work will be done to reduce the drift.

In testing the cryogenic gyroscope to separate various sources of drift, it is useful to be able to reverse the field that leviates the rotor rapidly enough so that the rotor will not fall in the process. A method for doing this has been successfully demonstrated and is reported in JPL SPS 37-36, Vol. IV.

PUBLICATIONS

1. Jeffers, W. A., Jr., and Whitney, W. M., "Temperature and Frequency Dependence of Ultrasonic Absorption in Liquid Helium Below 1°K," Phys. Rev., Vol. 139A, pp.1082-96 (1965).

2. Whitney, W. M., "Velocity of Sound in Liquid Helium Near 1°K," JPL SPS 37-36, Vol. IV.

3. Harding, J. T., "Force on a Superconducting Sphere in a Magnetic Field: The General Case," JPL SPS 37-34, Vol. IV, p. 81.

4. Harding, J. T., "Flux Reversal in Shorted Superconducting Coils," JPL SPS 37-36, Vol. IV.

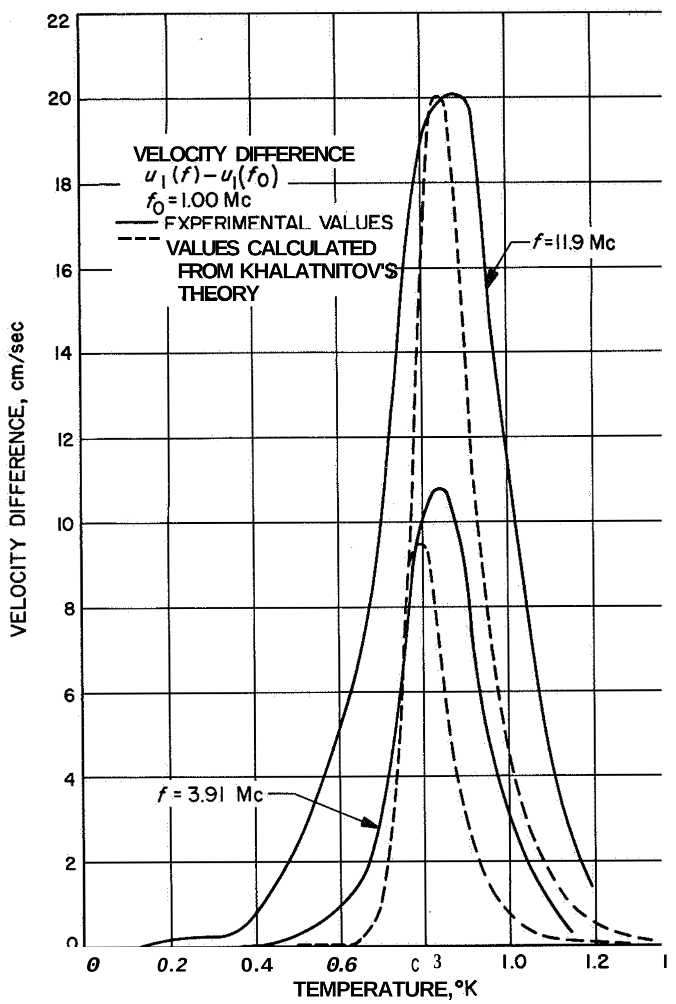


Fig. 1. Velocity differences plotted against temperature of liquid helium

LOW TEMPERATURE PHYSICS

NASA Work Unit 129-02-05-04-55
JPL 329-20401-1-3280

D. D. Elleman

BJECTIVE

The objective of this work unit is to measure and understand a variety of ındamental low temperature phenomena. Current emphasis: magnetic fields pro- iced by rotating and nonrotating superconductors in zero or small applied field, ;tempts to achieve and measure absolute zero field, high-resolution multiple- ·radiation nuclear-magnetic-resonance studies, high-magnetic-field phenomena ı superconductors, and study of the Fermi surface of selected metals using the e Haas-van Alphen effect.

OW FIELD SUPERCONDUCTIVITY

Work has continued on the study of magnetic fields produced by rotating and onrotating superconducting cylinders and cylindrical shells in zero and small applied agnetic fields (about 20 γ). These experiments are a continuation of the study of e London moment that has been successfully measured at JPL and reported in the erature. It has been found that nonrotating superconducting lead cylindrical shells oduce spontaneous fields as large as 100 γ when the shells are made to go super- nducting in a zero (less than 1 γ) applied field. The magnitude of the spontaneous trapped field is of a random nature, and the field may be either positive or gative. Also, small applied external axial fields have no measurable effect on e magnitude or sign of the trapped field. It has also been seen that the trapped eld is quite nonuniform and can have relatively large nonaxial components pproximately 20 γ or less).

Thermal switches have been added to the superconducting shells so that a ction of the shell may be driven normal and the persistent current interrupted.

It was found that when the thermal switch was activated, spontaneous fields 100 γ or less could be produced and trapped with zero applied external field. It s also found that very nearly the same field was trapped each time the switch was tivated, so long as the position of the switch was not changed. When the position the switch was changed a new value of trapped field was observed. It is believed ıt thermal gradients in the superconductor are responsible for producing the per- stent currents and fields. Experiments have been conducted with superconducting td solenoids in a manner similar to that described earlier, and comparable fields ve been seen. The results from the superconducting solenoid experiments tend confirm the hypothesis that thermal gradients produce the persistent currents d fields in the superconducting material.

Understanding these thermal gradient effects is an important step toward goal of producing absolute zero fields,

Experiments have also been conducted with large superconducting lead shells out 5 in. diameter and 12 in. length) that have hemispherical bottoms attached to shells. It was seen that when these shells were made to go superconducting m the center of the hemispherical bottom outward, a relatively large Meissner effect was seen. That is, when the superconducting shell was made to go superconducting in an ambient axial field of 40 γ, a field of 1γ was measured in the center of the shell. This technique will be quite useful in producing very low and well-shielded magnetic regions.

A magnetically shielded "mu room" has been designed and constructed. The mu room will be used in the low field superconductivity experiments. The mu room has inside dimensions of 6 x 6 x 6 ft. It has been designed so that it will fit in a conventional laboratory and is also portable. This design gives two distinct advantages: (1) convenient accessibility to laboratory equipment and facilities; (2) control of the ambient temperature of the mu room, which gives greater stability to the shielded region inside the mu room. The room now has a 20 γ region at the center of the room with a maximum gradient of 2 γ/ft at the center.

DE HAAS-VAN ALPHEN STUDIES

Work on the study of the Fermi surface of metals using the de Haas-van Alphen (dHvA) effect has continued. A new method for the analysis of the complex wave form from the dHvA experiments has been developed at JPL. This new method of analysis has two important features:

1. It yields directly the frequencies and amplitudes of all the component waves in the experimental waveform.

2. It effectively improves the signal-to-noise ratio of the experimental system.

Briefly, the method consists of FM-recording the raw data from the modulated field magnetometer with a magnetic-tape recorder. The data is then digitized so that it may be fed to a digital computer where a Fourier analysis (using 1/H in place of time) is performed. The computation is performed by taking the Fourier transform of the auto-correlation function. Because this is an integrative process, the signal-to-noise ratio improves as the length of the run is increased. The computer output is a plot of mean-squared voltage frequency and shows sharp peaks at all dHvA frequencies, Preliminary results with tin show the three highest frequency peaks for the [001] field direction. The sharpest peak has a resolution of 5%. The modulated-field magnetometer with detection at the second harmonic frequency is used to obtain the raw dHvA data. Figure 1 is a schematic diagram of the system. Field modulation is derived from the 14-kc oscillator. The harmonic content of the oscillator signal is reduced by the low-pass filter. After filtering, the signal is amplified by a low distortion power amplifier and applied to the modulation coil around the sample in the 50-kilogauss superconducting magnet. A second harmonic signal is produced by the sample because of the nonlinear relationship between the applied field and the sample magnetization. The signal from the detection coil is passed through a 28-kc band-pass filter to attentuate the 14-kc component and then is amplified and finally rectified after synchronous detection. The rectified signal, which exhibits the dHvA oscillation of the form

$$V\left(\frac{1}{B}\right) = \sum_n A_n (B) \sin \left(2\pi F_n \frac{1}{B}\right) + \Gamma_n$$

as the magnetic field is slowly swept, is FM recorded on magnetic tape for later computer analysis,

Work is now in progress to improve the computer program so that a finer grain mesh is used in sampling the data. This will improve the resolution of the program and allow us to look for higher frequency dHvA oscillations.

The experimental equipment for the de Haas-van Alphen studies has been moved to a new laboratory during the reporting period. The move is now completed and experiments will resume.

NUCLEAR MAGNETIC RESONANCE

The nuclear-magnetic-resonance (NMR) experiments are done in conjunction with S. Manatt, who is supported by the Materials Branch. The NMR experiments are progressing along two distinct and separate courses:

1. High resolution multiple-irradiation NMR studies.

2. Wide line nuclear magnetic studies of soil and rock samples.

The multiple irradiation studies are designed *so* that complicated NMR spectra may be simplified by irradiating certain portions of the spectrum with high intensity irradiation. Also, the relative signs of the spin coupling constants are obtained by the technique of "tickling."

During this reporting period, much of the time has been spent in preparation of the manuscripts for papers that are cow completed or near completion. These papers are listed at the end of this report.

The other area of NMR studies is the investigation of water content of rock and soil samples. This is a feasibility study to see if it is possible to find the moisture content of rock and soil samples with the large laboratory NMR spectrometer at our disposal. Experiments we have conducted show that water content as small as 0.19% H_2O by weight can be detected and measured. Table 1 gives a summary of results of some typical terrestrial samples.

Also, experiments have been conducted to find out if it is possible to build a small transitorized NMR spectrometer for possible flight experiments to measure moisture content of lunar and planetary samples. Such a spectrometer has been constructed and tested for sensitivity. Figure 2 shows the circuit diagram for the spectrometer. Moisture content as small as 2% by weight was measured with a signal-to-noise ratio of 7:1. This particular spectrometer requires several milliwatts of power and weighs approximately 3 oz, not including the magnet.

LIST OF PUBLICATIONS

1. Hildebrandt, A. F., and Elleman, D. D., "Thermoelectric Effect in Superconducting Lead," JPL SPS 37-35, Vol. IV, September 1965.

2. Elleman, D. D., Pearce, C. D., and Manatt, S. L., "Magnetic Resonance Studies of Soils and Rocks. I. A Preliminary Proton NMR Study," JPL SPS 37-34, Vol. IV, July 1965.

3. Manatt, S. L. and Elleman, D. D., "Analysis of the NMR Spectra of the Vinyl Protons of Cyclopentadiene and Cyclohexodiene Using Spin Decoupling," 150th Meeting of the American Chemical Society, Atlantic City, New Jersey, September 15, 1965.

4. Manatt, S. L., Juvinal, G. L., Wagner, R. I., and Elleman, D. D., "NMR of Phosphorus Compounds II the Relative Signs of Spin Spin Coupling Constants in Dimethylphosphine and Metlylphosphine, J. Am. Chem. Soc. (to be published).

5. Elleman, D. D., Pearce, C. D., Casanova, J., and Manatt, S. L., "The Signs of the $^{14}N-H^1$ NMR Coupling Constants of Ethyl and Iso-Propylinsonitrile," (manuscript completed).

6. Elleman, D. D. and Manatt, S. L., "The Analysis of the Proton NMR Spectra of 3Methyl-but-1-yne-2-ene," (manuscript completed).

7. Manatt, S. L., and Elleman, D. D., "Field Stabilization of NMR Spectrometer by Utilization of Sample Co-axial and External to the Receiver Coil," (manuscript completed).

Table 1. Terrestrial soil sample data

Sample	Area measured	Corrected area	lensity, g/cc	Weight % ^1H	Gravimetric air dry weight % H_2O	Weight % H_2O
Blank	-36	0	-	-	-	-
Gunflint chert	-32	4	1.3 (chipped rock)	0.02 1	-	0. 19
Calibration sample of 1% $(C_6H_{12}O_6)_n$ glass beads	-	15	1.5	0.067	-	0.60
69-1-wet	2 13	249	1.3	1.3	3.8	12.0
69-1-dry	158	194		1.0		9.0
17-wet	2 15	251	1.0	1.7	2.0	15.2
17-dry	50	86		0.58		5.2
2-1-wet	9	45	1.6	0. 19	0.3	1.7
2-1-dry	-7	29		0.12		1.1

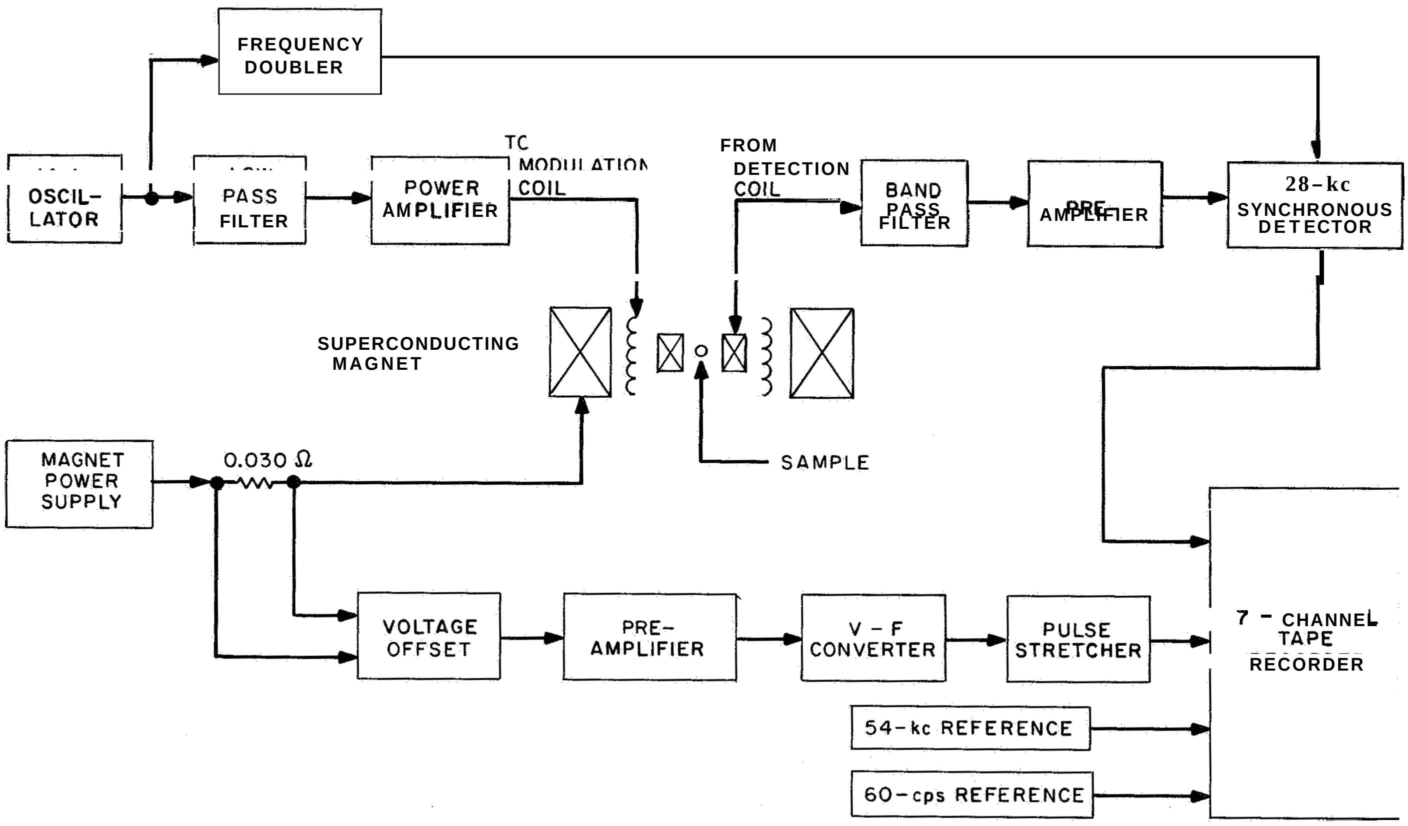


Fig. 1. De Haas - van Alphen effect data acquisition system

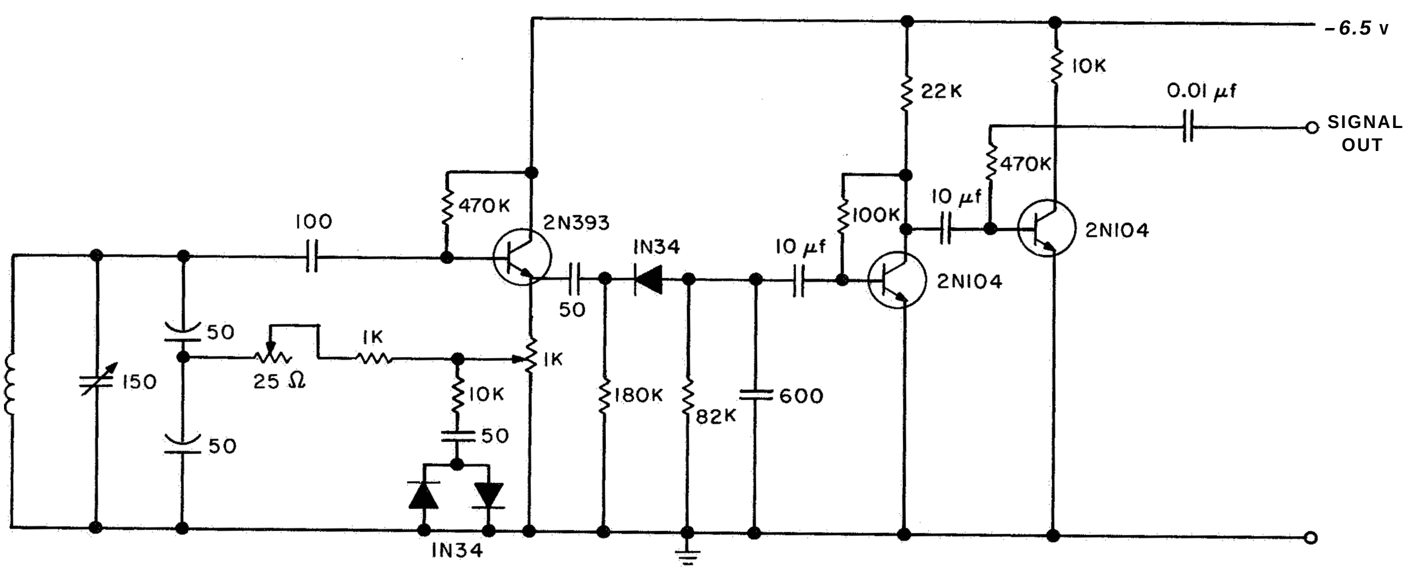


Fig. 2. Sample coil

MAGNETICS AND THERMOELECTRICS RESEARCH

NASA Work Unit 129-02-05-06-55
JPL 329-21401-1-3450

D. I. Tchernev
D. S. Herman

›BJECTIVE

One objective of this work unit is to conduct research in magnetism that may ≥ad to a demonstration of the feasibility of very high density magnetic digital com- uter memories, and of direct analog magnetic storage of photographic images. he immediate objective is to find the variation of the nuclear magnetic resonance NMR) frequency of Fe^{57} with density for iron-oxide particles uniformly dispersed ı a nonmagnetic binder.

The other objective of this work unit is to conduct research that will lead to better understanding of the thermoelectric effect, especially in thin films. The ɔng-range objective of this work is to provide improved thin film thermoelectric ıfrared detectors for lunar and planetary horizon scanners. A study will be made E the electrical transport properties of thin semimetal and semiconductor films. he thermoelectric, resistive, Hall coefficient, and magnetoresistance properties re the ones to be measured. From the observation of these properties as a function E temperature, a knowledge will be obtained of the mechanisms contributing to ıese properties in thin films. An immediate objective is to find the necessary con- ttions for achieving bulk thermoelectric power and resistivity in these thin films .e., how thin film parameter variations affect film properties).

[AGNETIC INTERACTION BETWEEN γ-Fe_2O_3 PARTICLES

During the reporting period the construction of the NMR superheterodyne ɔectrometer was completed and the equipment tested over the range from 10 to) Mc. During this period we also acquired and installed a 12-in. precision .boratory electromagnet. The complete equipment with the magnet is shown in ig. 1. A detailed description of this equipment will be prepared for the JPL SPS ɔon.

The spectrometer covers the frequency range from 10 to 250 Mc with an :curacy better than 1 part in 10^7, and is capable of operation with specimen mperatures down to 4.2°K. The performance of the equipment was tested using ımples of water doped with copper chloride. In the applied field of the laboratory agnet, the NMR of the hydrogen proton was seen in the range from 10 to 50 Mc. ecause the nuclear resonance frequency of the proton is 42.57 Mc for a 10-kilogauss agnetic field, the upper limit of the test was the maximum available magnetic field 12-kilogauss from the electromagnet with the given 3-in. gap. The observed gnal-to-noise ratio was better than 40 db without the lock-in amplifier. The latter lds an improvement in the signal-to-noise ratio of at least 20 db, plus the con- ence of finding the exact resonance frequency (a zero crossing instead of a aximum point).

The next step in this work will be to search for the NMR of the Fe^{57} nucleus γ-Fe_2O_3. We have completed some preliminary studies that show the range of equencies of interest will be between 50 and 80 Mc, depending on temperature;

however, because the equipment is capable of a much larger range and because the signal-to-noise ratio can be at most 100 times (40 db) less than the one for water (the natural abundance of Fe^{57} is 2% and there is added dilution in the binder), we are confident that this will not represent any significant problems. For establishing the signal-to-noise ratio of the Fe^{57} nuclear signal, the equipment is now in the process of being calibrated with samples of yttrium iron garnet (YIG) where the Fe^{57} resonance has been studied recently and the frequency is accurately known.

During the next 6 mo the major emphasis of the magnetics research effort will be in materials and sample preparation. After measuring the interaction between the iron-oxide particles and establishing the minimum distance at which two magnetic bits of information can be stored before they cease to be independent, we shall try to find methods for the preparation of samples capable of such optimum density storage. This will involve experiments of uniform dispersion, proper binder materials, and methods for producing uniform thin layers of such materials:. The sample and material preparation will also serve to aid the magneto-optic efforts of the optical physics research task in the same Section at JPL.

Other magnetic materials, different than iron oxide, will also be studied with the NMR spectrometer. This will include Permalloy thin films and other possible magnetic high density storage media.

THERMOELECTRIC THIN FILMS

Three systems have been constructed for performing studies on thin thermoelectric films. The first is a high vacuum ($\sim 10^{-8}$ Torr) system for the deposition of most of the films. This system will be used for evaporation of elemental semimetal films and also for compound and alloy film evaporations. A number of important film parameters such as rate of deposition, thickness, and film annealing temperature can be known and controlled within this vacuum system. Evaporations can be made simultaneously into four substrates. Also, a glass substrate is provided for monitoring the resistance of the film during and after deposition. Figure 2 is a photograph of the inside of the evaporation system showing the major components of the system. The metals are evaporated from a resistance heated source onto three different substrates. The first substrate (from left to right in the top of Fig. 1) is a quartz crystal located in an oscillating electrical circuit used for finding film thickness. The second is a resistance rate monitor that finds and controls the rate of evaporation. The third is the substrate holder having the capability of simultaneous evaporation onto four glass or single-crystal substrates. A mask permits the films to be deposited onto the glass or single-crystal substrates in a predetermined configuration. A heater is located on the rate monitor so that the resistance of the film can be measured as a function of temperature without opening the vacuum system. A heater is also located on the substrate holder so that the substrate temperature can be controlled during and after the evaporation.

The second system is used for measuring the thermoelectric and resistive properties of the films as a function of temperature. This system has the capability of operating down to liquid helium temperatures although most tests will be confined to the range between liquid nitrogen temperatures and 100°C. A photograph of this system is shown in Fig. 3. The films are mounted in a closed container located inside the double Dewar (shown in white) capable of holding liquid helium, The closed container is evacuated by the vacuum system to keep the films from coming into direct contact with any fluids. The films are mounted on a structure that permits them to be heated from the low temperature of the environment up to 150°C. The measuring instruments used for the temperature, thermoelectric, and resistance measurements are shown on the left and right sides of Fig. 3. These instruments are mainly potentiometers and associated equipment.

The third system, which is close to completion (the other two have been completed), fits inside the pole pieces of a large laboratory magnet {capable of 12 kilogauss) and will be used to measure the Hall coefficient and the transverse magnetoresistance of the same films mentioned earlier. These measurements will be performed as a function of temperature over the range of 77 to 373°K.

Only preliminary and very sketchy results have now been obtained for bismuth (a semimetal) films. These results show that the films have a negative temperature coefficient of resistance (TCR) of $-0.003/^{\circ}C$, and do not have bulk resistivity. The reasons for a negative TCR are probably caused by occlusions and/or disordered structure in the films that alter the complex band structure of bismuth enough to make the films act as semiconductors rather than metals. The failure to achieve bulk resistivity can be attributed to scattering of the current carriers by the film boundaries besides probable scattering effects from the occlusions and/or disordering in the films.

In the next report period, added transport properties for the bismuth films will be investigated, especially the effect on the properties of varying the thickness. The film parameters will be varied to see their effect on the properties, One parameter that might give interesting results is the growing of epitaxial films on single-crystal substrates of sapphire, Mg0, and NaCl.

Through the generosity of the Research Division of Autonetics, single-crystal films of near intrinsic silicon on sapphire substrates will be given to us. These films have been grown by the chemical decomposition of either $SiCl_4$ or SiH_4. The transport properties mentioned earlier will be measured for these films as a function of temperature and film thickness.

PAPER PRESENTED

D. I, Tchernev, "Frequency-Dependent Anisotropy in Si- and Ca-Doped YIG and LuIG," paper presented to the 11th Annual Conference on Magnetism and Magnetic Materials, November 16 – 19, 1965, San Francisco, California.

Fig. 1. NMR superheterodyne spectrometer and electromagnet

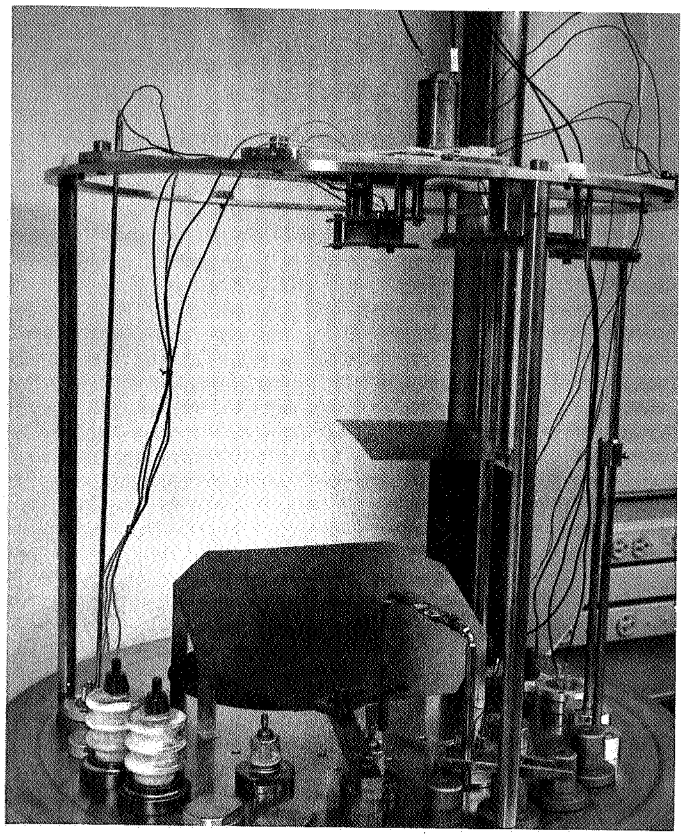


Fig. 2. Thermoelectric thin film evaporating equipment

Fig. 3. Apparatus for measuring thermo-electric power and resistance of films as function of temperature

SEMICONDUCTOR RESEARCH
NASA Work Unit 129-02-05-09-55
JPL 329-21801-1-3450

A. Shumka
J. Maserjian

OBJECTIVE

The objectives of this work unit are to do research in semiconductor physics leading to a better understanding of various electronic devices, and to demonstrate the feasibility of new semiconductor electronic devices. Two immediate objectives are: (1) to obtain and investigate space-charge-limited electron current flow in germanium, and (2) to explain the mechanisms of electrical conduction and of charge storage in thin films of titanium oxide.

SPACE CHARGE LIMITED CURRENT IN GERMANIUM

During this report period, a systematic electrical and metallurgical characterization of all the solid-state diodes fabricated at JPL was made. These results are summarized in JPL SPS 37-35, Vol. IV, and show that the fabricated structures are suitable for investigating space-charge-limited (scl) electron current in germanium. Current-voltage (I-V) characteristics were measured on 13 germanium $n^+ \pi n^+$ solid-state diodes of various base-width, at ambient temperatures of 273, 195, and 78°K. An I-V characteristic of a solid-state diode at an ambient temperature of 78°K is shown in Fig. 1. Preliminary analysis of the results showed that pure scl electron current in germanium follows a three-halves power law. This relationship between current and voltage is anticipated from the theory for field-dependent mobility of the form $\mu \sim E^{-1/2}$ where μ is the mobility and E the electric field. For samples in which the applied electric field was greater than 5×10^3 v/cm the current tended to become directly proportional to the voltage as would be expected from carrier velocity saturation. More detailed analysis is necessary to establish this further. The earlier reported inconsistency between sample base-widths as calculated from the I-V characteristics and the punch-through voltage has been resolved by making a more accurate determination of the acceptor doping density in the π-region and by using electrical measurements made at 273°K instead of 300°K.

A vacuum evaporator has been obtained, and construction of a vacuum chamber apparatus for deposition of material from two independent sources is nearing completion. This will make it possible to deposit alloying material on both sides of the π-type germanium wafers without breaking vacuum.

During the next report period a detailed analysis of the I-V characteristics of the fabricated solid-state diodes as a function of temperature, base-width, and junction area will be carried out to characterize more specifically scl electron current in high-purity π-type germanium. More solid-state diodes will be fabricated, if necessary, to extend the ranges of the base-width and the junction area. Measurements of I-V characteristics at smaller temperature intervals may be required to find the temperature dependence of scl electron current in germanium. The new vacuum facility will make it possible to fabricate $n^+ \pi p^+$ structures. Space charge current flow caused by double injection can be investigated in these structures.

TITANIUM-OXIDE THIN FILMS

Work during this reporting period has been concerned with the continued development of a physical model that provides a consistent interpretation of the observed properties of titanium oxide films. The experimental work was performed, in most part, before this report period, with the exception of the data shown in Figs. 2 and 3. As explained in the last semiannual report (Ref. 1), the model being developed explains the electrical conductivity of titanium oxide films by means of a mechanism that is intermediate between pure tunneling and thermionic emission. Such an intermediate process arises quite naturally if large impurity or defect concentrations are assumed to be present in the oxide. As was also pointed out in the last semiannual report, there is strong justification for this assumption with regard to a high density of oxygen vacancies in our titanium oxide films.

In the model that is being developed, the effect of the high density of oxygen vacancies is to produce very narrow space charge layers in the oxide adjacent to each aluminum contract. Because these space charge barriers are very narrow (on the order of 30 **Å)** allows electron tunneling to occur between the aluminum contact and the titanium oxide. It turns out that the shape of the barriers is such that thermal activation may be required before electron tunneling occurs. That is, the electrons require enough thermal energy to make much more probable quantum mechanical transitions through the barrier. The details of the theory of this process are too lengthy to be included here, but will be published separately soon. A fit of the theory to the experimental results obtained from a typical sample is shown in Fig. 4. This figure applies only for the limit of zero field where the theory is much simpler. The experimental points were obtained by extrapolating the low field data to zero field. The quantities ϕ and T_O given in Fig. 4 are two parameters for which values are selected to give the best fit between experiment and theory. The quantity ϕ is the barrier height, and T_O is a characteristic temperature mainly found by the space charge density in the barrier.

The barrier height, ϕ , was independently found from photo-response measurements that gave a value of 1.24 ev, in good agreement with the value of 1.30 ev used to obtain the best fit between experiment and theory. The characteristic temperature, T_O, of 420°K may be compared with certain capacitance measurements as discussed below and is also found to be consistent. The overall agreement of the theory with the experimental low field conductance is thought good considering the simplifying assumptions that were used, particularly an assumption that the oxygen vacancies are the main source of impurity states and are uniformly distributed throughout the titanium oxide.

Measurements of the capacitance and of the conductance of the same sample as a function of frequency at two temperatures are plotted in Figs. 2 and 3 respectively. The large temperature dependence of the capacitance is particularly interesting because it cannot be explained based on any well known theory. For example, the effect of change of dielectric constant with temperature is much too small to account for this change. Based on the same space charge model discussed here, an expression can be derived for the effective barrier thickness that depends on temperature and has the same characteristic temperature, T_O, as a parameter. The theoretical change in the barrier capacitance when the temperature is changed from room temperature to liquid nitrogen temperature is consistent with the experimental data when the value of the characteristic temperature is taken to be 420°K, the same value used earlier.

The dependence of capacitance and conductance on frequency can be explained if the effect of electron trapping in the impurity states on the space charge capacitance is included. The theory of such a mechanism was introduced by **A.** Rose (Ref. 2) and has been considered further by others (Refs. 3 and 4). This should be proper here because we are dealing with extremely high concentrations of impurities. The effect of trapping is important at low frequencies where the occupancy of traps can follow the field oscillations. This may be conveniently represented in an equivalent circuit by a capacitance C_T and resistor R_T as shown in Fig. 5, (see Ref. 4). The important features of the dependence of both the conductance and the capacitance on frequency can be satisfactorily interpreted in terms of the equivalent circuit given in Fig. 5. It may be noted that this equivalent circuit is different from the equivalent circuit given in the last semiannual report. In the earlier circuit, the effects of electron trapping were not included. Also, in the earlier circuit a separate equivalent circuit was shown for each barrier (separated by R_o, representing the resistance to the main part of the oxide); in Fig. 5 the combined effects of both barriers are represented by C_B and R_B, and R_o is neglected. Finally, the resistance of the metal film leads, R_s, has been added in Fig. 5.

A detailed analysis of the results in terms of the proposed ideas depends on the assumptions made about the impurity distribution. This problem is now under study for providing an accurate theoretical description. Future plans are to incorporate the conclusions of this study into a complete description of the results that will be submitted for publication. Added experimental measurements will be designed to further test the validity of the theory,

REFERENCES

1. Maserjian, J. , JPL SPS 37-31 Vol. IV, p. 98 (1965).

2 Rose, **A.** , Phys. Rev. Vol. 97, p. 1538 (1955).

3. Lampert, M. , Phys. Rev., 103, p. 1648 (1965).

4. Muller, R. S. , "Theoretical Admittance Variation with Frequency in Insulators Having Traps Subject to Charge Injection." Physics of Semiconductors, Proc. 7th Intern. Conf., Academic Press, Paris, p. 631 (1964).

CONSULTING WORK

1. J. Maserjian and A. Shumka present weekly lectures on semiconductor electronics to engineers from all divisions at JPL. Subjects covered during this report period include: (1) basic properties of semiconductors, (2) metal oxide semiconductor devices, (3) hot electron diodes, (4) high current effects in diodes and transistors, (5) metal to semiconductor contacts, and (6) carrier generation and recombination in P-N junctions.

2. Technical evaluation of a proposal for a heterojunction device to be used as a photodetector.

3. Technical evaluation and discussions concerned with a Texas Instruments proposal for a photon coupled switch consisting of a gallium arsenide (GaAs) light-emitting diode packaged together with a photodetector.

4. Technical evaluation and discussions concerned with custom MOS field effect transistor integrated circuits to be used for low level commutation in a lunar and planetary horizon scanner.

PUBLICATIONS

A. Shumka, "Some Electrical and Metallurgical Properties of the Fabricated Germanium Solid-state Diodes," JPL SPS 37-35, Vol. IV, p. 49.

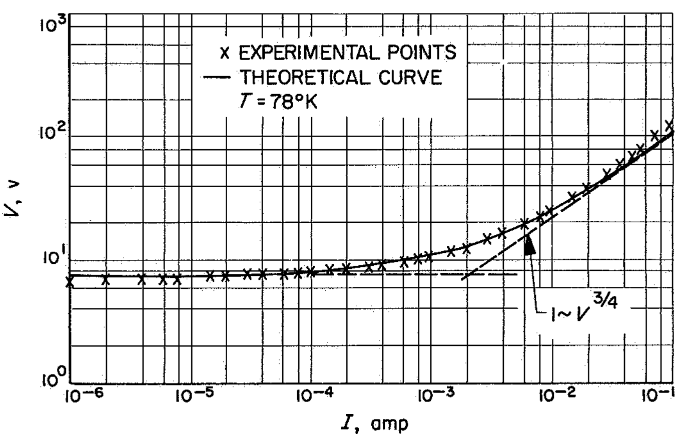


Fig. 1. Comparison between theory and experiment for scl current in n - π - n germanium structure at T = 78°K ($W = 110\ \mu$, $A \simeq 3.8 \times 10^{-3} cm^2$, $N_A \approx 10^{12} cm^{-3}$, and $V_pt = 7.6$ v)

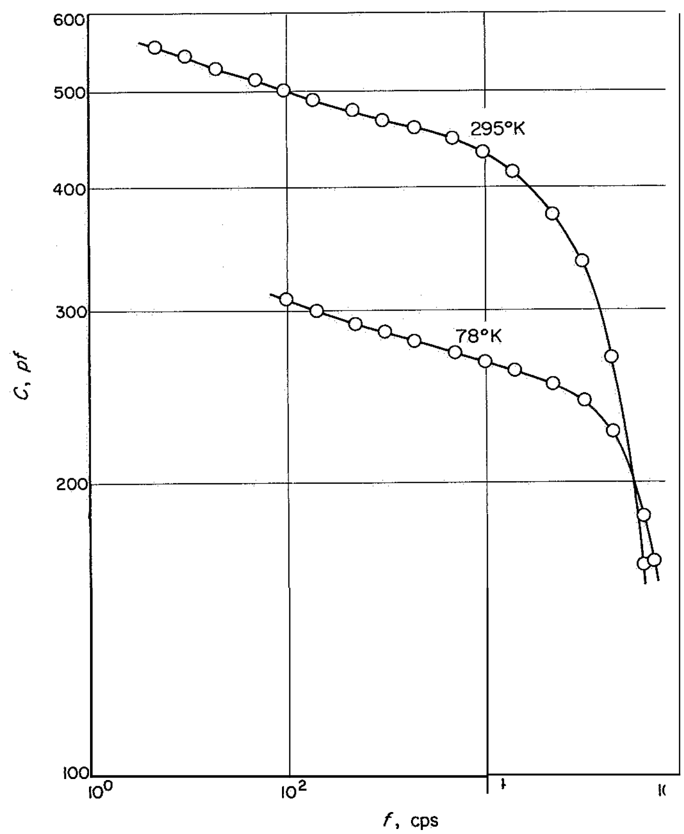


Fig. 2. Zero field conductance per unit area vs reciprocal absolute temperature (normalized)

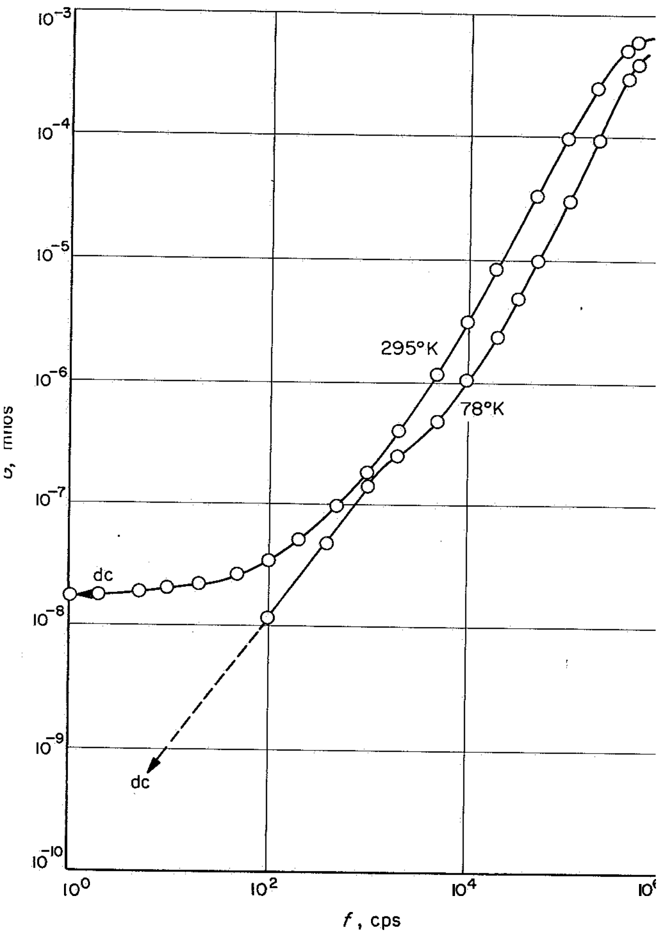


Fig. 3. Capacitance vs frequency at room temperature and liquid nitrogen temperature

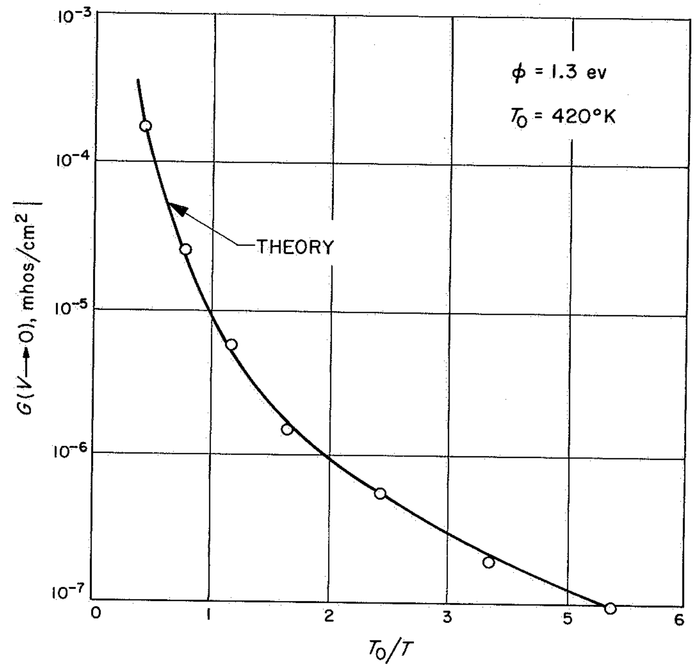
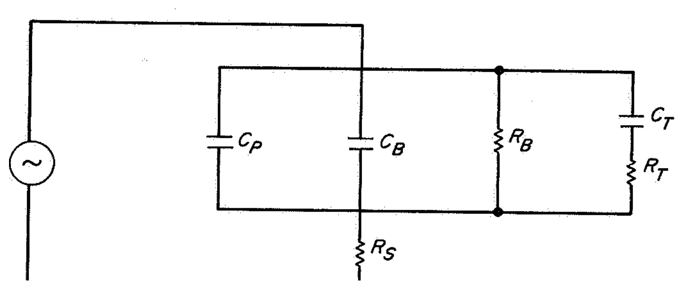


Fig. 4. Conductance vs frequency at room temperature and liquid nitrogen temperature



C_B = TOTAL BARRIER CAPACITANCE

C_T = EFFECTIVE CAPACITANCE OF DISTRIBUTED TRAPS

C_P = PLATE CAPACITANCE

R_B = TOTAL BARRIER RESISTANCE

R_T = EFFECTIVE RESISTANCE OF DISTRIBUTED TRAPS

R_S = SERIES RESISTANCE OF METAL FILM LEADS

Fig. 5. Equivalent circuit of sample

3

THEORETICAL PHYSICS

NASA Work Unit 129-02-07-02-55
JPL 329-20901-1-3280
F. B. Estabrook
H. D. Wahlquist
J. S. Zmuidzinas
E. Klevans
C.-S. wu
M. M. Saffren

OBJECTIVE

The objective of this work is to increase theoretical understanding at the forefront of modern physics. Specific activities are described in the following paragraphs.

INTERACTION OF HIGH–INTENSITY RADIATION WITH MATTER

M. M. Saffren is studying the scattering of intense photon beams by matter from a new theoretical standpoint. The scattering is described in terms of the change in the photon correlation functions. Such a description takes into account the "internal structure," or many-photon aspect, of an intense beam, not merely its intensity. The description treats beams on an equal footing regardless of their degree of coherence so that no formal distinction has to be made between, say, a (totally incoherent) beam with a definite photon number and a (completely coherent) beam with a definite phase.

This approach has shown that the S-matrix element usually used in describing scattering by an intense n-photon beam is, in reality, the n-photon correlation function of the beam; it is <u>not</u> the 2-photon correlation function that actually is observed in scattering experiments.

Two applications of this general approach are being considered. The first is to the scattering of an intense beam by a single electron (Thompson scattering). Here there is no internal structure to the scatterer, but the scattering does modify the n-photon correlation functions. The second application is to the calculation of the diffraction of an electron by an intense photon standing wave (Kapitza-Dirac effect). Here the internal structure of the standing wave affects the electron scattering. This effect is of a higher order than has been calculated earlier, and experiments have been reported in the literature showing that correlation effects may be important.

SPS Contributions:

1. Cumming, G. D., "Correlation and Exchange Corrections to the Long-Wavelength Phonon Dispersion Relation," JPL SPS 37-34, Vol. IV, July 1965.

2. Saffren, M. M., "Interaction of an Electron with the Photon Field," JPL SPS 37-36, Vol. IV, November 1965.

PLASMA PHYSICS

A general study of high-frequency conductivity in plasmas is almost complete. Parts I and II have been published ("High-Frequency Conductivity of a Plasma in Quasi-Equilibrium. I. Formulation of the General Theory," Phys. Rev., Vol. 138, A51, 1965; and "High-Frequency Conductivity of a Plasma in Quasi-Equilibrium. II. Effect of a Uniform Magnetic Field," Phys. Rev., Vol. 140, A118, 1965, by C.-S. Wu) and a manuscript of Part III is in preparation. In Part III, the case is considered in which electron temperature considerably exceeds the ion temperature. The resistivity is found to be greatly enhanced because of the excitation of incoherent ion waves in the plasma.

The mathematical structure of the dielectric function of a two-temperature plasma has been investigated. Such a study provides good understanding of the resonance phenomena for the frequency range near the ion wave frequency. This is very important for understanding the transport properties of a two-temperature plasma. A paper that describes the results of this research is in preparation.

An added problem that has attracted our attention is the discovery of unstable transverse waves in a plasma with an anisotropic ion distribution. Such an instability has not been earlier discussed in the literature. The result of our study was reported by C.-S. Wu to the APS, Plasma Physics Division Meeting (November 8-11) at San Francisco. The paper was titled "Transverse Electromagnetic Instabilities in Plasma."

Three research papers on our work in plasma theory will appear in the Proceedings of the International Conference on Phenomena in Ionized Gases, Belgrade, Yugoslavia (August 1965). They are (1) by E. H. Klevans and J. R. Primack, "Collision-Induced High-Frequency Instability in a Fully Ionized Plasma"; (2) by E. H. Klevans, C.-S. Wu, and J. R. Primack, "High-Frequency Conductivity Calculation Using the Plasma Kinetic Equation"; and (3) by C.-S. Wu, "Kinetic Equation for an Inhomogeneous Plasma in a Uniform External Magnetic Field."

SPS Contributions:

Wu, Ching-Sheng, "Transverse Electromagnetic Instabilities in a Plasma," JPL SPS 37-36, Vol. IV, November 1965.

RELATIVITY

An investigation of Born-type rigid motions in Einstein spaces has been completed, and will appear as JPL TR 32-868, Rigid Motions in Einstein Spaces, by H. D. Wahlquist and F. B. Estabrook. A shorter version has been accepted for publication by the Journal of Mathematical Physics, to appear in the spring of 1966. For Einstein space-time of nonuniform curvature, all irrotational, nonisometric rigid motions have been explicitly found. Rotating rigid congruences in Einstein space-time of nonuniform curvature have been shown to have no degrees of freedom, and the validity of the Herglotz-Noether theorem in Einstein space-time has been shown to depend on a complete set of 14 first order total differential equations.

Work on the general dyadic method for general relativity theory has continued. The introduction of scalar and vector potentials for the acceleration and angular velocity fields have always been shown to be possible; these not only show the close analogy of some inertial phenomena in space-time to electromagnetism, but provide a powerful analytical tool. An investigation is also in process to find what especially convenient (or canonical) reference frames may, in general, be introduced into a given space-time by the dyadic method.

Maxwell's equations in dyadic form for arbitrary reference frames in gravitational fields have been obtained and are being used to investigate electromagnetic fields in arbitrary space-time geometry. The remarkable result of Robinson (J. Math. Phys., Vol. 2, p. 290, 1961) for null fields (that the propagation vector generates a shear-free, null, geodesic congruence) has been recovered in dyadic terms, and a similar analysis of the properties of more general, polar and axial, fields is in process.

SPS Contributions:

Wahlquist, H. D. and Estabrook, F. B., "Relativistic Rigid Frames in Gravitational Fields," JPL SPS 37-35, Vol. IV, August 1965.

ELEMENTARY PARTICLE THEORY

The first phase of the work on the internal symmetry problem of elementary particles has been completed and is being published as Unitary Representations of the Lorentz Group on Four-Vector Manifolds, JPL TR 32-797, by J. S. Zmuidzinas. A condensed version of this report is being readied for publication in the open literature.

A discussion of unitary representations of the Lorentz group on four-vector manifolds has been completed. An abstract of preliminary results was published in Bull. Am. Phys. Soc., Vol. 10, p. 712 (1965), titled, "Unitary Representations of the Lorentz Group on Four-Vector Manifolds," by J. S. Zmuidzinas. The complete paper has been accepted for publication by the Journal of Mathematical Physics, to appear in the spring of 1966.

Some progress has been made on the dynamical problem of fundamental particles, considered from the viewpoint of "operator bootstraps."

SPS Contributions:

Zmuideinas, J. S., "Construction of Invariant Scattering Amplitudes," JPL SPS 37-35, Vol. IV, August 1965.

MATERIALS RESEARCH *(129-03)*

CERAMIC MATERIALS

NASA Work Unit 129-03-04-01-55
JPL 329-31101-1-3510

M. Leipold
P. Becher

OBJECTIVE

The ceramic materials research effort is directed toward the measurement and understanding of the mechanical behavior of ceramic materials. The work is divided into two parts. The major program is concerned with the role of grain boundaries and associated impurities in the mechanical behavior of polycrystalline ceramics. Related to this problem is the understanding of the structure and nature of the grain boundary and distribution of impurities associated with it. To accomplish this goal, precise mechanical studies are being made on a well characterized ceramic (magnesium oxide). The emphasis in these studies will be on the interaction of cracks with grain boundaries and grain boundary deformation. Besides these mechanical studies methods will be developed for finding the composition of a real ceramic grain boundary and of the theoretical structure of a pure grain boundary. The second, subsidiary portion of this ceramic materials research effort is concerned with the mechanical behavior of a polycrystalline carbide ceramic (tantalum carbide). Here the effort will be to find the broad mechanical behavior and to define areas requiring added, more concentrated studies.

MAGNESIUM OXIDE

A common denominator of both parts of this program is finding precise mechanical properties and, therefore, a considerable effort has been placed on the development of a test facility for such evaluations. The test facility described earlier (JPL TM 33-243) has been moved to a new location and is again operating. A high-pressure gas supply has been installed and is operating for the air floated bearings. A water cooling system for the environmental chamber has been connected and checked; a pumping system for the vacuum environment, when required, is in place to be connected. Electrical utilities have not been completed and control portions of the system are now operating using temporary electrical connections.

The special dual range load cell has proved to be unsatisfactory in its original design. The linearity was unsatisfactory and the high range provided less than half the desired capacity. It is being used in its present form with load calibrations until a new unit can be completed.

Calibration of the existing load cell and strain detection systems has been made. Preliminary evaluations of nonaxial stresses have shown them to approach the present limit of detection— about 1%. Evaluation of the test facility should be completed during the next report period. This will provide a complete mechanical testing facility for use with brittle ceramic materials.

Fabrication of magnesium oxide (MgO) test specimens for study of grain boundary mechanical behavior has continued. Two vendors capable of grinding the required specimen shape have been evaluated. Both proved to be satisfactory;

however, one later met difficulty and is unwilling to make further attempts. As a possible alternative to the present uniaxial hot-pressing, fabrication of MgO blanks by hot isostatic pressing has been contracted. The results have not yet been obtained.

Studies of the impurities associated with grain boundaries in MgO have produced several far reaching conclusions. These are:

1. Impurities in MgO are segregated to the grain boundaries when the total quantity of impurity present is far below the equilibrium solubility limit; for example, calcium oxide present at about 50 ppm atomic is segregated to the grain boundary at temperatures where the equilibrium solubility limit is about 5 wt %.

2. Impurities may form multiple phases at the grain boundary; for example, calcium and silicon oxide form one discreet impurity phase at the grain boundary in MgO, while aluminum oxide is located in an entirely separate impurity phase.

3. The lack of visible second phase at a grain boundary is not enough evidence to neglect impurity segregation.

4. Anion impurities are significant in MgO.

5. Many impurities in MgO are introduced in the form of agglomerate but the presence of such agglomerates is not related to the ultimat existence of segregated impurities.

The in-house effort on the evaluation of impurity distribution in MgO will be reduced during the coming period because the limits of detection of presently available techniques are being approached; however, contract effort will be placed on the development of improved techniques of such studies.

The development of a theoretical model for a pure grain boundary in MgO has been started. Random network theory, which has had success in the description of the structure of glasses, has yielded a model for any interface in an ionic material. The model is based on variations in the coordination number near the interface between a crystal lattice and another phase. Evaluation of this model will continue.

During this reporting period, a publication titled "Fabrication of High Purity Polycrystalline Magnesium Oxide" has been accepted for publication in the <u>Bulletin of the American Ceramic Society</u>. "Mass Spectrographic Analysis of Non-Conducting Ceramics" appeared in the September issue of the <u>Journal of the American Ceramic Society</u>. **A** paper titled "Impurity Distribution in MgO" was presented at the Western Meeting of the American Ceramics Society in October. This paper has been completed for submission to the <u>Journal of the American Ceramic Society</u>.

TANTALUM CARBIDE

Finding mechanical properties of tantalum carbides will be conducted in the same test facility developed for the MgO studies. Therefore, the research effort in this portion of the program has concentrated on the fabrication of satisfactory tantalum carbide (TaC) specimen blanks. Considerable difficulty met in this fabrication has shown that: (1) the hot-pressing characteristics of TaC are strongly influenced by stoichiometry; (2) the various lots of tantalum carbide obtained from a commercial source showed considerable variation in stoichiometry, both from lot to lot and from grain to grain within a given lot; (3) evaluation of the stoichiometry of the as-received powder was not enough and/or sensitive enough to predict the hot-pressing characteristics. It was necessary to conduct analysis on pressed compacts (influenced by changes in the material during pressing) to obtain any correlation between material parameters and pressing characteristics. Table 1 shows such variation in pressing ease and certain other characteristics of selected lots of powder obtained under the same specification. Note the increase in lattice parameter of compacts with increased density.

Percent of theoretical density after 1 hr at 1800°C and 7000 psi	Particle size, A	Lattice Parameter, A	Grain size, μ	Lattice Parameter, A
81	641	4.451	2.5	4.444
85	452	4.451	20	NA
97	415	4.449	25	4.447
99	330	4.453	25	4.449
100	950	4.453	40	4.452

NA = Not Available

The presence of small agglomerates was also noted in the as-received tantalum carbide powders. These have been analyzed, by various techniques, to be: (1) Ta_2C, (2) C, or (3) HfO_2. It is expected that all three, in reality, are present in the material. In general, these agglomerates may be removed by proper screening leaving strained material generally free from such contamination. Blending of the various lots of TaC powder has been completed and routine production of specimen blanks has started.

CHEMICAL ANALYSIS CONTRACT

Part of the ceramic materials research effort has been directed toward development of the improved analytical techniques for use with refractory materials by Sperry Rand Research Center (SRRC) under JPL Contract 950992. Results have shown that mass spectroscopy provides generally acceptable bulk analyses for impurities in MgO. Some added confirmation for certain anion impurities is needed. Present and future effort will be placed on finding hydroxl contamination in MgO and on the development of techniques for finding impurity distribution.

Some analytical emphasis by SRRC has been placed on analyses of TaC. Successful analyses have been conducted for metallic impurities and for oxygen; however, a satisfactory technique for the tantalum-carbide ratio does not seem to be available.

Monthly letter reports and quarterly summary reports detailing the techniques developed and the results obtained by SRRC are available. Also, a report titled "Analysis of Nitrogen and Oxygen by Spark Source Mass Spectrometry" has been approved for external publication.

During the earlier reporting period the Western Regional Meeting of the American Ceramic Society was attended in Los Angeles. During the forthcoming period, the Fourth Annual Symposium on Fundamental Phenomena in the Materials Science Topic-Fracture will be attended at Boston in January, and the American Ceramics Society National Meeting in May in Washington, D. C.

CARBON AND GRAPHITE

NASA Work Unit 129-03-04-02-55
JPL 329-31601-1-3510

D. B. Fischbach

OBJECTIVE

The current carbon and graphite research program consists mainly of investigations on the mechanisms of plastic deformation and failure at high temperatures, and the kinetics and mechanism of the graphitization transformation. There is a strong emphasis on the influence of microstructure on properties and metallographic, x-ray diffraction and electronic measurement techniques are being used. The principal material of interest is pyrolytic carbon, although limited studies on other carbon materials such as glassy carbon and conventional coke-pitch carbons are continuing. A more thorough fundamental understanding of the behavior of carbons and graphites is important for effective engineering use of these materials and for the development of improved carbon materials.

CARBON AND GRAPHITE

The investigation of the shear deformation of pyrolytic carbon parallel to the substrate plane has continued (Ref. 1). Optical microstructure studies as well as the effect of various pretreatments show qualitatively that the shear flow stress σ_f depends sensitively on the degree of preferred orientation (dewrinkling) of the basal planes in the shear direction. The x-ray diffraction preferred orientation measurements on samples cut from the deformed regions of double-shear specimens have confirmed this qualitative conclusion. However, this measurement has proved difficult and a quantitative specification of the structure dependence has not yet been achieved. Further investigation has failed to confirm an earlier suggestion that the. preferred orientation of compression annealed pyrolytics might decrease on reheating without stress. Added data has been obtained on the dependence of σ_f on strain rate $\dot{\epsilon}$ over the temperature range 2500 – 2900°C using the double-shear specimen configuration. Analysis of this data shows that $\dot{\epsilon} \simeq \sigma_f^3 S \exp(-\Delta H/RT)$ where S is some function of the microstructure. Arrhenius plots of both the strain-rate data at constant flow stress and the flow-stress data at constant strain-rate (measured earlier) give an effective activation energy AH of about 260 kcal/mole. This is in very good agreement with the activation energy values obtained earlier for tensile creep parallel to the substrate and for graphitization (in both pyrolytic and conventional carbons). This constitutes strong evidence for a fundamental diffusion mass-transport process with this activation energy in graphitizing carbons and graphite, but the detailed mechanism remains uncertain.

A JPL TR has been published on the structure and tensile properties of glassy carbon (Ref. 2) and a small amount of work is continuing on the investigation of the structure of this material. The results of an investigation of the high temperature creep behavior of pyrolytic carbon parallel to the substrate have been discussed in a JPL TR (Ref. 3), which is in the process of publication, and an observation on the analysis of earlier obtained creep data was reported (Ref. 4). The abstract of a proposed paper on mechanisms of high temperature deformation in pyrolytic carbons (Ref. 5) has been submitted to the Electrochemical Society to be considered for inclusion in the Symposium on Graphite to be held in Cleveland in May 1966. A note on preferred orientation parameters has been accepted for publication [Ref. 6).

Preparations are continuing for further studies on the mechanisms of high temperature tensile deformation parallel to the substrate in pyrolytic carbons. A new lot of pyrolytic carbon has been procured for these studies and it has been characterized by microstructural and x-ray diffraction studies in both the as-deposited and heat-treated conditions. Tensile specimens are being machined from both as-deposited and heat-treated material. Several modifications of the tensile and creep deformation apparatuses are being made to improve capabilities and performance. A jig and clamp assembly, designed to help handle the load train assembly without damaging fragile deformed or heat-treated speciments, has been fabricated. The bellows seal between the furnace and the lower pull rod is also being modified for the same reason. The creep testing procedure has been improved with a "constant rate" loading device, but some further modifications will be required to obtain best results from this device.

The results of investigations on the kinetics of graphitization of undeformed pyrolytic carbons have been discussed in detail in a JPL TR (Ref. 7). Work has continued on the effect of plastic deformation on graphitization kinetics in pyrolytics (Ref. 8). Measurements of the temperature distribution in both the tensile and creep furnaces have shown that the temperature is essentially uniform over the gage length, but the butt ends of the specimen are 50 – 100°C cooler than the center. Because of this temperature gradient, direct comparison of the structures of deformed gage and undeformed butt sections of the same sample, used earlier, does not yield valid data on the influence of deformation on graphitization, Instead, the degree of graphitization in the gage section of samples deformed in the creep apparatus has been compared with that of samples given the same heat treatment in the same apparatus under zero stress. Also, the degree of graphitization of the gage and butt (taking account of the temperature gradient) sections has been compared with the degree of graphitization expected from earlier studies of the kinetics of graphitization of the same lot of pyrolytic carbon. These measurements have confirmed that a large enhancement of the degree of graphitization results from tensile deformation parallel to the substrate in excess of about 3% elongation. The effect of deformation is equivalent to a 250 – 300°C increase in temperature.

Under plans reported earlier, JPL Contract No. 950112 with Barogenics, Inc., to design and construct a high-pressure apparatus for melting carbon was stopped on December 31, 1965. When stopped, the pressure vessel shell and end closures had been fabricated, pressure-proof tested to 7500 psi, and certified as an unfired pressure vessel in the states of Ohio and California. A final report documenting the progress made in the design of the complete apparatus and the design problems that remain unsolved was prepared by Barogenics.

It is anticipated that the carbon and graphite activities will be relocated in two new buildings during the second half of FY 1966. This relocation will temporarily impede research activities, but will result in improved facilities for future research. Investigations on deformation mechanisms, especially in very well-oriented pyrolytics, will be continued. It is planned to write technical reports on shear deformation of pyrolytic carbons parallel to the substrate, the kinetics of graphitization of conventional carbons, and the structure sensitivity of the magnetic susceptibility.

REFERENCES

1. Kotlensky, W. V., "Basal Plane Shear in Pyrolytic Carbons," JPL SPS 37-35, Vol. IV.

2. Kotlensky, W. V., and Fischbach, D. B., Tensile and Structural Properties of Glassy Carbon, JPL TR 32-842, November 15, 1965.

3. Kotlensky, W. V., Analysis of High Temperature Creep in Pyrolytic Carbon, JPL TR 32-889 (to be published).

4. Kotlensky, W. V., and Fischbach, D. B., "Creep Data Analysis," JPL SPS 37-36, Vol. IV.

5. Fischbach, D. B., and Kotlensky, W. V., "On High Temperature Deformation Mechanisms in Pyrolytic Carbons," abstract submitted to Electrochemical Society for presentation at Symposium on Graphite, Cleveland, May 1966.

6. Fischbach, D. B., "Preferred Orientation Parameters for Pyrolytic Carbons," J. Appl. Phys. (to be published).

7. Fischbach, D. B., Kinetics of Graphitization, I. The High Temperature Structural Transformation in Pyrolytic Carbons, JPL TR 32-532 (to be published).

8. Fischbach, D. B., "Deformation-Enhanced Graphitization in Pyrolytic Carbons," JPL SPS 37-36, Vol. IV.

JPL Technical Memorandum No. 33-272, Vol. II

THERMAL STABILITY OF POLYMERS AT HIGH TEMPERATURE

NASA Work Unit 129-03-11-02-55

JPL 329-30301-1-3820

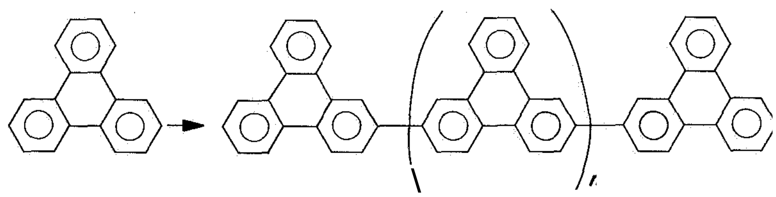
J. D. Ingham
G. K. Ostrum
D. D. Lawson

OBJECTIVE

The objective of this work unit is to improve the tractability and usefulness of high temperature polymers.

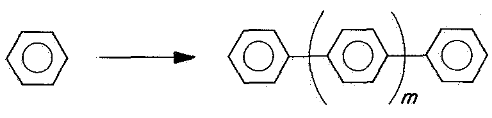
POLY (TRIPHENYLENE)

As a part of our work on studies of the applicability of fused salts as reaction media and studies of the molecular structure of poly (aromatics) we have polymerized triphenylene in a eutectic mixture of ferric chloride (60 wt %), sodium chloride (26 wt %), and potassium chloride (14 wt %).



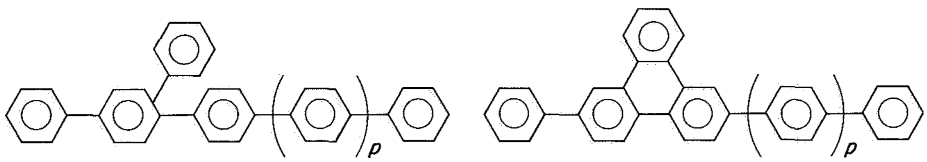
TRIPHENYLENE POLY (TRIPHENYLENE)

Because one of the primary difficulties in the preparation and processing of poly(aromatics) is their insolubility in common solvents, fused salts are being studied as reaction and processing media. Although poly(benzene) is often assumed to be all para or 1,4-:



BENZENE **POLY** (BENZENE)

it is possible that it contains branches or crosslinks that could form triphenylene nuclei:



BRANCHED POLY (BENZENE) ONE TRIPHENYLENE NUCLEUS

Such structures would decrease the solubility and tractability of the polymer and, therefore, it is desirable to find out if they are present. Because of this, triphenylene was polymerized, so that the resulting polymer could be compared with poly(benzene) with respect to infrared spectra, solubility, and other characteristics. Because pronounced similarities have been seen, it is now believed that poly(benzene) does contain some poly(nuclear) structures. This work will be continued during the next 6 mo to further find the structure of poly(aromatics). The work described here has been submitted for publication in the JPL SPS and to Chemical Communications.

ISOSTATIC PRESSING OF HIGH-TEMPERATURE POLYMERS

A part of our work on high-temperature polymers includes investigation of ways of processing available polymers for general application to flight projects, Because many of the polymers; e.g., poly(benzene); are infusible, insoluble, and intractable, one method of forming them into usable shapes is to sinter or cold press the polymer powder. One such method that we are studying is isostatic pressing, as shown in Fig. 1. The polymer to be compacted is packed and sealed in a rubber or plastic mold around a metal core. The filled plastic mold is inserted in a perforated metal form of the correct contour. The mold is then immersed in a hydraulic fluid in a pressure vessel. An hydraulic pump exerts a pressure of – 20,000 psi or more in a true three-dimensional squeeze through the liquid to the pliable mold, compressing the polymer powder to the desired shape. The mandrel and perforated support can be omitted for some solid shapes. It is expected that this process could be advantageously applied to the cold-forming of refractory inserts for combustion chambers and nozzles as well as for elastomeric or pliable tank liners and bladders. Our effort will be largely devoted to establishing its value and limitations with respect to high temperature polymers and polymer mixtures. A small isostatic press has been ordered and delivery is expected by about February 1966.

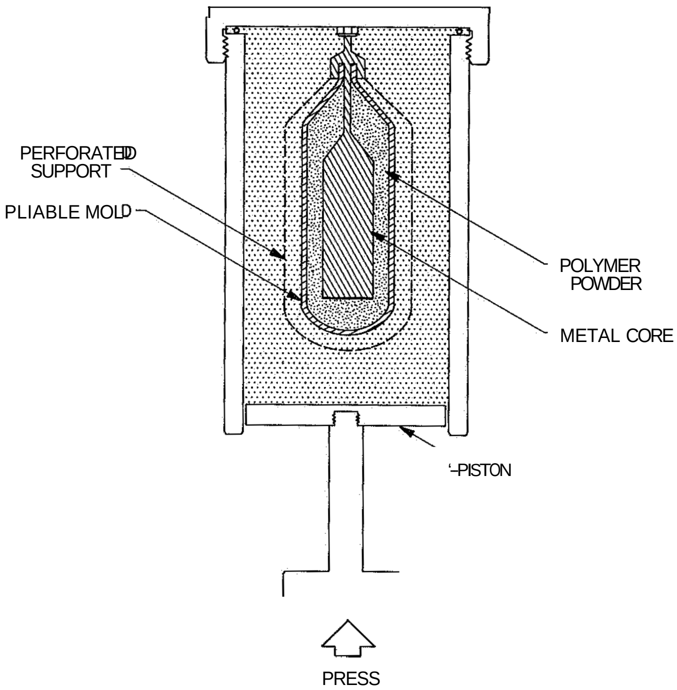


Fig. 1. Isostatic pressing

JPL Technical Memorandum No. 33-272, Vol. II

ELECTRICAL PROPERTIES OF POLYMERS

NASA Work Unit 129-03-11-03-55
JPL 329-30401-1-3820

A. Rembaum
J. Moacanin
A. Hermann

OBJECTIVE

The objectives of this work unit are the elucidation of the mechanism of energy transfer in polymeric semiconductors and a study of the electron transfer to vinyl aromatic polymers with emphasis on reaction equilibria.

ENERGY TRANSFER IN POLYMERS

Investigations of the effect of an electron transfer from sodium to polyacenaphthylene were continued. The polyacenaphthylene-sodium complex was found to undergo more extensive chain scission at low temperature than at high temperature. To prove the earlier proposed mechanism of chain scission, the electron transfer to the monomeric unit (acenaphthene) was studied by means of the electron spin resonance (ESR) technique. This study showed that acenaphthene reacts with sodium to form radical ions and the concentration of these ions increases as the temperature is lowered, reaching a maximum at about -65°C. The phenomenon is reversible and sodium was found to precipitate at room temperature. Therefore, the system undergoes an equilibrium reaction similar *to* the one described earlier for substituted aromatic hydrocarbons (Ref. 1). Finding the equilibrium constant as a function of temperature by two independent methods, namely spectrophotometry and ESR, yielded an enthalpy change for this reaction equal to 6. 5 kcal/mole.

Based on the experimental hyperfine structure, a theoretical ESR spectrum was derived.

CONDUCTIVITY

To elucidate the electrical conduction properties of poly-N-vinylcarbazole-iodine complexes the following studies were carried out:

1. Finding Hall effect by an ac technique.
2. Finding free spin concentration as a function of temperature by ESR.
3. Finding the Seebeck coefficient.

Table 1 shows the variation of the Hall mobility of poly-N-vinylcarbazole complexed with iodine in various proportions. The magnitude of the Hall mobility and sign of the Hall coefficient are in agreement with the results of the drift mobility findings for single crystals of pure iodine (Ref. 2). To try to correlate unpaired spins and charge carriers it was found that the density of carriers deduced from Hall data is at least four orders of magnitude smaller than the concentration of free spins found by ESR. Finding the activation energy of unpaired spins confirmed that the electrical carriers cannot be identified with the unpaired electrons detected by ESR experiments. (Details of these results were published in JPL SPS 37-35, Vol. IV, p. 115.)

The recently built apparatus for finding the Seebeck coefficient was found to yield data with an accuracy of at least 10%. The Seebeck coefficient was found as a function of temperature and the results are shown in Fig. 1.

The Seebeck coefficient increases as the temperature decreases and the results are analogous to those obtained for inorganic semiconductors; e. g., germanium (Ref. 3

OPTICAL PROPERTIES

A study was made of the optical absorption of poly-N-vinylcarbazole films complexed with varying amounts of tetracyanoethylene (TCNE). The optical absorption coefficient for the charge-transfer band increased linearly with increasing TCNE content, but reached an asymptotic value at about 8 – 9 mole %. These results show that, at most, one TCNE can complex with eight vinylcarbazole moieties. This observation is consistent with the earlier result that electrical conductivity for PVCA-TCNE reaches an asymptotic value for the 8 – 9 mole % composition. This work was reported in JPL SPS 37-35, Vol. IV.

This study will be extended to the N-ethylcarbazole-TCNE system.

FUTURE ACTIVITIES PLANNED

To confirm the hyperfine structures of the ESR spectrum of the acenaphthene radical ion, the effect of solvent and alkali metal will be studied. Finding the ESR spectrum of a 1,2 dideuteroacenaphthene radical ion should allow a complete theoretical interpretation of the electronic interaction between the alkali metal and acenaphthene. This will complete the study of energy transfer in polyacenaphthylene and permit concentration on the mechanism of electrical conduction in organic polymers. To elucidate the conduction mechanism of poly-N-vinylcarbazole-iodine complexes, more mobility data are necessary. Therefore, a new Hall mobility apparatus will be constructed.

Similar studies to those carried out earlier (i.e., free spin concentrations, Seebeck coefficients, pressure and temperature effects on resistivity) will be continued on samples of poly-N-vinylcarbazole of various molecular weights. An exploratory synthesis of other potentially low resistivity polymers will be undertaken.

PAPERS PRESENTED

A. Hermann and A. Rembaum, "Hall Mobility and ESR of Polyvinylcarbazole-Iodine Complexes," American Chemical Society, West Coast Regional Meeting, Los Angeles, November 1965; and American Physical Society Meeting, Los Angeles, December 1965.

J. Moacanin, A. Rembaum, and R. Laudenslager, "Theta Dimensions of Polyacenaphthylene," American Chemical Society, West Coast Regional Meeting, Los Angeles, November 1965.

NEW CONTRACTS

JPL Contract No. 951326, titled "Synthesis of Atactic and Stereo-regular Vinylaromatic Polymers and a Study of These Reactions with Alkali Metals," was awarded to the Stanford Research Institute.

JPL Contract No. 951408, titled "Research and Development Study on the Relations Between Viscosities and Thermodynamic Properties of Moderately Concentrated Polymer Solutions," was awarded to the University of Southern California.

REFERENCES

1. Rembaum, A., Eisenberg, A., and Haack, R., "Equilibria Between Metallic Sodium and Aromatic Hydrocarbons," J. Am. Chem. Soc., Vol. 87, No. 10, May 20, 1965.

2. Hermann, A. M., and Ham, J. S., Rev. Sci. Instr. (to be published).

3. Begalle, T. H., and Hull, G. W., "Seebeck Effect in Germanium," Phys. Rev., Vol. 94, No. 5, June 1, 1954.

Table 1. Hall mobility in poly-N-vinylcarbazole: iodine complex at room temperature

Iodine, wt %	Hall mobility, $cm^2/v\text{-}sec$	Sign of Hall coefficient
34	0.5	Negative
40	0.2	
56	0.3	Negative
77	0.7	Negative
100 (single crystal, ac plane)	2.9	Positive

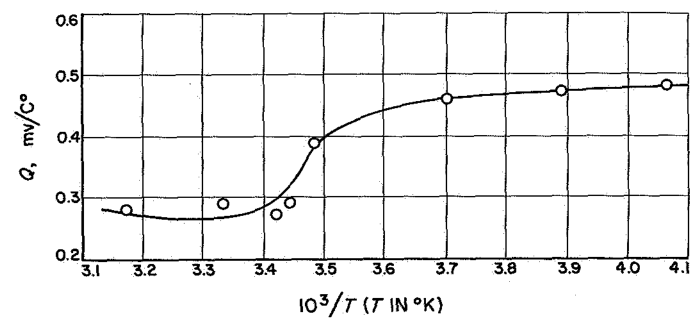


Fig. 1. Variation of Seebeck coefficient (Q) with temperature (T) for 34% iodine, 66% PVCA

RHEOLOGICAL PROPERTIES OF POLYMERS

NASA Work Unit 129-03-11-04-55
JPL 329-30501-1-3820

J. Moacanin
S. H. Kalfayan

OBJECTIVE

The objective of this work unit is to study the mechanisms of strong polar interactions in polymer networks, and the effect of morphology on the behavior of polyblends and copolymers.

During the last report period, the effect of polar forces on T_g and viscoelastic properties of poly(propylene oxide) was studied. These forces were introduced in the polyether system by dissolved lithium perchlorate. Results of this work were presented at the Symposium on Multiple Transitions in Polymers, ACS Meeting, Atlantic City, September 1965 and will be published in the Journal of Polymer Science.

A study has been started on the dielectric properties of the PPO-LP system. For the low molecular weight polyether (mol. wt. 2000), a high static dielectric constant was observed, which could be caused by rigid structures having a dipole moment of about 7 debyes. This interpretation is consistent with the observed viscoelastic properties as well as recent measurements of the steady flow viscosities. Dielectric measurements show a dispersion region at about 50 kc. Consulting services of Professor M. Baur have been secured for this study.

The operation of the torsion pendulum has been tested at liquid nitrogen temperature. A cryostat is being constructed for measurements at liquid helium temperature. It is planned to first study low temperature transitions for the PPO-LP system. Later studies will be extended to other polyethers such as poly(butylene oxide), as well as to graft copolymers and polyblends of vinylaromatic polymers prepared under contract for Electrical Properties of Polymers (NASA 129-03-11-03-55, JPL 329-30401-1-3820). The low temperature behavior of polymers has acquired considerable practical and fundamental importance in view of recent results showing that transitions below T_g may have a profound effect on properties such as impact resistance.

PURIFICATION OF CARBOXYL-TERMINATED POLY(ALKYLENE OXIDES) (PAO)

A scale-up of the synthesis of carboxyl-ending poly(propylene oxide) was tried. The cyanoethylation and hydrolysis of a 700-g batch of material did not pose any new problems. New difficulties, however, were encountered when the purification of the larger amount of crude carboxyl-terminated PPO was carried out. As a result the product obtained was less pure than formerly obtained with 100 – 150-g batches.

No catalytic effect was observed in the carboxyl-epoxide reaction when dibutyl tin dilaurate and tributyl tin oxide were used with carboxyl-terminated PPO and the triepoxide ERL 0510.

ORGANIC CHEMISTRY

NASA Work Unit 129-03-11-06-55
JPL 329-31501-1-3280
S. L. Manatt

OBJECTIVE

The objective of this work unit is to maintain, by study of properties of matter and the synthesis of molecules, a high level of competence in modern techniques of chemistry capable of contributing to study of electronic structures of molecules and atoms, solution of analytical chemistry problems, conception of space science experiments, development of new materials, study of energy transfer in matter, kinetics of reactions, development of instrumentation, structure of polymers, and the processing of experimental data.

Major emphasis has been on the application and development of nuclear magnetic resonance (NMR) techniques for quantitative and qualitative analyses of mixtures, study of molecular electronic structures, study of molecular energy transfer and rate processes, and space science experiments. Other work has involved synthesis of model compounds, for NMR studies and quantum mechanical calculation of molecular electronic structures.

HIGH-RESOLUTION NMR PROBLEMS

We are rewriting all our NMR computer programs for handling experimental data because of JPL input and output system changes on the IBM 7090. Also, we are writing a NMR program that will calculate spectra and automatically plot NMR spectra in one step. Studies of the very complicated ^{19}F and ^{1}H spectra of 1,1-difluoro-2-methylbutadiene are in progress. The analyses of the complicated ^{19}F spectrum of perfluoro-1, 3-butadiene and the ^{31}P, ^{19}F and ^{1}H spectra of $HCF_2CF_2PH_2$ have started,

ANALYTICAL APPLICATIONS

We have recently developed a NMR analytical method for analysis of H_2O in liquid N_2O_4 in the range of 0-1% H_2O. This analysis is important in support of the Surveyor propulsion systems. NMR analyses on a number of unknowns from the Bioscience Section (326) have been carried out. We continue to make NMR facilities available to various people in the Polymer Research Section (382).

INSTRUMENTATION

Recently we received and put into operation a Varian A-56/60 spectrometer, which replaced an older A-60. We have experienced many time-consuming breakdowns during the last few months, although the A-56/60 is a much more useful instrument.

The construction and successful testing of a simple breadboard wide-line NMR spectrometer for detection of protons in rocks and soils has been carried out. This transistorized spectrometer is powered by mercury batteries.

ORGANIC CHEMISTRY

A number of trifluoroacetyl derivatives of alcohols, amines, thiols, and phenols have been prepared and purified for NMR studies. Work on a ^{19}F NMR classification scheme for these organic groups has been continued. Molecular orbital calculations on some small-ring organic compounds have been carried out.

Modification of all our quantum mechanical programs for JPL's new IBM 7090 computer system has been necessary. We are in the process of modifying a SCF-MO-CI program from Shell Development Company so that it is usable at JPL.

PUBLICATIONS AND PRESENTATIONS

1. Berson, J. A., Evleth, E. M., and Manatt, S. L., "Nitrogen Analogs of Sesquifulvalene II. Theoretical Correlation of Ground-State Properties," J. Am. Chem. Soc., Vol. 87, p. 2901 (1965).

2. Evleth, E. M., Berson, J. A., and Manatt, S. L., "Nitrogen Analogs of Sesquifulvalene III. Theoretical Correlation of Excited-State Properties," J. Am. Chem. Soc., Vol. 87, p. 2908 (1965).

3. Mallory, F. B., Manatt, S. L., and Wood, C. S., "The Roles of Some Degenerat Rearrangements as Determined by Nuclear Magnetic Resonance Spectroscopy," J. Am. Chem. Soc., Vol. 87, p. 5433 (1965).

4. Manatt, S. L., Juvinall, G. L., Wagner, R. I., and Elleman, D. D., "NMR of Phosphorus II. The Relative Signs of the Spin-Spin Couplings in Dimethylphosphine and Methylphosphine," J. Am. Chem. Soc. (to be published).

5. Manatt, S. L., and Elleman, D. D., "Field Stabilization of NMR Spectrometers by Utilization of Samples Co-Axial and External to the Receiver Coil" (to be published).

6. Elleman, D. D., Pearce, C. D., Casanova, J., and Manatt, S. L., "The Signs of the ^{14}N-^{1}H NMR Coupling Constants in Ethyl- and iso-Propylisonitrile" (to be published).

7. Elleman, D. D., and Manatt, S. L., "The Analysis of the Proton NMR Spectrum of 3-Methylbut-1-yne-2-ene" (to be published).

8. Manatt, S. L., and Ellemen, D. D., "Analyses of the NMR Spectra of Cyclopentadiene and Cyclohexadiene Using Spin Decoupling" (to be published).

9. Manatt, S. L., "Molecular Orbital Calculations I. Some Cyclobutadiene Systems Joined with Two Cyclopropenyl, Cyclopentadienyl or Cycloheptatrienyl Ring" (to be published).

10. Manatt, S. L., "Molecular Orbital Calculations II. A Treatment of 1,3-π-Interaction in Cyclobutenyl Systems" (to be published).

11. Manatt, S. L., "Characterization of Functional Groups by NMR. I. Classification of Alcohols from the ^{19}F Spectra of Trifluoroacetates" (to be published).

12. Ingham, J. D., Lawson, D. D., Rapp, N. S., Hardy, J., and Manatt, S. L., "Characterization of Functional Groups by NMR. II. Identification of the Nature of the Hydroxyl Groups in Poly(propylene Oxides) via the ^{19}F Spectra of Their Trifluoroacetates" (to be published).

13. Manatt, S. L., and Elleman, D. D., "Analyses of the NMR Spectra of the Vinyl Protons of Cyclopentadiene and Cyclohexadiene Using Spin Decoupling," presented at the 150th Meeting of the American Chemical Society, Atlantic City, New Jersey, September 15, 1965.

14. Manatt, S. L., "The Classification and Characterization of Organic Functional Groups by a Trifluoroacetylation-^{19}F NMR Technique," presented at the Western Regional Meeting of the American Chemical Society, Los Angeles, California, November 18, 1965, invited paper.

15. Lawson, D. D., Ingham, J. D., and Manatt, S. L., "Molecular Structure and Configuration of Polymers. The ^{1}H and ^{19}F NMR Spectra of Poly(alkylene Oxide) Terminal Groups," presented at the 13th Canadian High Polymer Forum, Ottawa, Canada, September 22, 1965.

SOLID STATE MATERIALS
NASA Work Unit 129-03-15-04-55
JPL 329-31001-1-3510

P. Shlichta
I. Weinberg

OBJECTIVE

The objective of this work unit is to gain a better understanding of the interrelationship between crystal perfection and the mechanical properties of solids, and the interrelationship between defect structures and the electronic properties of solids. Research is now concerned with sodium chloride crystals, Taylor wires, transport properties, and superconducting thin films.

SODIUM CHLORIDE CRYSTALS – P. Shlichta

Further analysis of the earlier reported bend test data on as-grown sodium chloride crystals has led to an extrapolated yield stress ($\{110\}$ shear) of 18 g/mm^2 for ultra-high purity rods. This is less than half the lowest value reported earlier for annealed cleavages of commercial purity.

A limited number of preliminary compression tests on ultra-high purity solution-grown crystals (supplied by Dr. P. M. Gruzensky, National Bureau of Standards, Boulder, Colorado) led to an estimated yield stress value as low as 6 g/mm^2. Because of the limited number of tests and the lack of time to make a complete analysis, this value should not be taken as conclusive.

Contract work on the purification of sodium chloride to remove cation and anion impurities to a level of about 1 ppm has been completed. Thin single crystal rods were grown from this material in the modified crystal grower, but there was not enough time to test these.

Oral presentations of the results of this work were made at UCLA, University of Denver, and the American Physical Society meeting in December. Because of a reduction in manpower quota, all work on sodium chloride crystals was stopped on December 30, 1965.

TAYLOR WIRES – P. Shlichta

The modification of the Taylor wire drawing equipment was continued with the time and manpower available. As completed, the equipment has independent speed controls for the feed mechanism and for the take-up mechanism. The synchronization of these controls was not carried out.

Work also continued on finding the causes of the discontinuities in the drawn filaments. Vacuum casting of the metal before swaging into wire did not eliminate gas bubbles. Techniques for evaluating residual gases in vacuum cast metal slugs were used, but the preliminary results obtained were inconclusive. It was found that molten metal did not wet silica glass in air or argon but strongly adhered to it in vacuum. This ability to control the glass-to-metal adhesion in the Taylor wire drawing process could be an important factor. Because of a reduction in manpower quota, all work on Taylor wires was stopped on December 30, 1965.

THERMOELECTRIC POWER IN METALS AND ALLOYS – I. Weinberg

Niobium-Zirconium Alloys

Analysis of data on the thermoelectric power in niobium-zirconium alloys has been completed. Indications are that thermoelectric power can be used to obtain information regarding the Fermi surface in transition element alloys where the usual Fermi surface exploratory tools are inadequate. Data were taken on niobium and niobium containing 1, 1.8, 3.8, and 20 atomic % zirconium. The most outstanding feature is the occurrence of a large phonon drag peak at 80°K. Progressive attenuation of this peak is observed for zirconium contents up to 3.870. Resurgence of the phonon drag peak is seen for the 20% alloy. Appearance of the large phonon drag peak in these samples is attributed to distortion of the Fermi surface in contact with the Brillouin zone. Attenuation of the phonon drag peak is attributed to a combination of lattice distortion and changes in the Fermi surface that tend to favor normal over umklapp electron-phonon interactions. A change in the character of Fermi surface contact with the Brillouin zone is shown by resurgence of the phonon drag peak for the 20% alloy. Soon, careful consideration will be given to experiments that will exploit use of thermoelectric power and possibly other transport properties in studying the Fermi surface of niobium-zirconium and other transition element alloys. The results of this work to date are contained in a manuscript titled "Thermoelectric Power in Niobium-Zirconium Alloys," by I. Weinberg and C. W. Schultz, which has been accepted for publication in the Journal of Physics and Chemistry of Solids.

Copper Alloys

Experiment and analysis have been completed for dilute alloys of gold and silve respectively, in copper. This is a continuation of the work on Cu-Si and Cu-A1 alloys in which attenuation of the phonon drag peak was used to study the mechanisms whereb lattice waves (phonons) are scattered by impurities. For Cu-Au, the results show tha phonons are scattered by the mechanism of mass difference while in Cu-Ag, phonons are scattered mainly by the elastic strain field associated with the solute atom. Because of the assumptions made in theoretical treatment of the data it appears advisable to use materials whose phonon drag peak occurs at very low temperatures. Therefore, several dilute silver alloys have been selected for future study.

The following publications have resulted from this work.

1. Weinberg, I., "Phonon Drag Thermopower in Dilute Copper Alloys," Physical Review (to be published).

2. Weinberg, I., "Attenuation of Phonon Drag Thermopower in Dilute Copper Alloys, Paper for oral presentation at American Physical Society Meeting, Durham, Nort Carolina, March 1966.

3. Weinberg, I., "Phonon Drag Thermopower in Dilute Copper Alloys," JPL TR (to be published).

4. Weinberg, I., "Phonon Drag Thermopower in Cu-A1 and Cu-Si Alloys," Physical Review, Vol. 139, A838 (1965).

TUNNELING BETWEEN SUPERCONDUCTORS (Josephson Tunneling) – I. Weinberg

Flux quantization and microwave generation have been observed through the dc current-voltage characteristics of Pb-O-Pb Josephson junctions operating at 4.2°K. Superconducting bridges (Mercereau Circuits) have been successfully fabricated and flux quantization effects observed through the dc current-voltage characteristics. An ac detection scheme using phase sensitive amplification has been designed and initial steps taken in its construction. During the reporting period, a thin film thickness monitor and interferometer were placed in operation resulting in a large improvement for reproducibility in junction fabrication. In the next reporting period, work will continue on the ac detection scheme and magnetometer applications will be explored.

LUNAR DUST GENERATION, TRANSPORT AND ADHESION

NASA Work Unit 129-03-16-01-55
JPL 329-31701-1-3510
W. F. Carroll

OBJECTIVE

The objective of this work unit is to develop basic knowledge of the generation of dust from probable lunar surface materials under high vacuum conditions, and to study the transport and adhesion properties of this generated dust. Such information would aid in the development of "nonstick" surfaces, removal techniques, or other means of preventing or removing dust build-up from surfaces landed on the Moon.

PROGRESS

An analysis of the factors affecting the investigation has been made including a review of similar existing programs and the probable productivity of various approaches,

During the second quarter of FY 1966, a contract was negotiated for lease of a high vacuum station for performance of the experimental part of the program. Such a lease arrangement will provide a cost saving over procurement of a vacuum station, and permit suitable performance of the program within the approved budget.

Procurement and fabrication of the test chamber and related test equipment for grinding under high vacuum are in process. Experimental work is expected to start during the third quarter of FY 1966 and preliminary results will be reported by the end of the year.

APPLIED MATHEMATICS (129-04)

APPLIED MATHEMATICS

NASA Work Unit 129-04-01-01-55
JPL 329-40101-1-3120
W. G. Melbourne

BJECTIVE

The objectives of this work unit are to conduct research in statistical ;timation theory, optimal control theory, applied mathematics, computer science udies, and general relativity.

CATISTICAL ESTIMATION THEORY

A paper describing the sequential estimation theory developed in Ref. 1 has :en accepted as a correspondence item by the IEEE G-AC Transactions; it is to be ıblished in the Spring 1966 issue. This sequential estimation technique has been ecifically applied to the orbit determination problem by C. G. Pfeiffer in a JPL ternal document. It was shown that the "weighted least squares" form of the estiate can be thought of as a discrete approximation of the continuous form of the timate, assuming Wiener process noise (integrated white noise) on the counted ppler data.

Some studies have been made on the nonlinear estimation problem but little ogress has been realized. Some of the preliminary results are described in two ᴾL internal documents by L. Joyce. Work is continuing to try to find better methods r parameter estimation than the classical linearization and iteration techniques now ed, and to establish the statistics of such estimates.

Methods for finding the statistics of the first occurrence of specified sequences symbols of a given coding alphabet have been established and a report will soon be ;ued describing these techniques and their extensions. The results are important studying the statistical properties and analysis of space communication messages.

ᴾTIMAL CONTROL THEORY

A paper developing a geometrical interpretation of an optimal trajectory ef. 2) has been tentatively accepted for pubiication by the Journal of the Franklin ;titute, pending revision. Some new results are obtained, and new interpretations earlier known results are given.

A paper describing a technique for optimal final value control of powered flight ıjectories (Ref. 3) has been accepted by the AIAA Journal, and should appear ɔrtly. This method was suggested by the analysis of Ref. 2.

Some extensions of Ref. 2 have been developed and, hopefully, will be pubhed later.

A study involving the optimization of the path of a power-limited thrusting ıicle in an inverse-square gravitational field where the kinetic power of the exhaust beam varies as a function of the radial distance of the vehicle from the gravicenter has been completed. As a result of the dependence of the thrust on a position varial an added term occurs in the usual optimal control equations defining the path of the vehicle in space. The results of this study have been incorporated in the JPL low-thrust trajectory program and numerical data are being generated for solar electric propulsion mission studies.

A theoretical study of the conjugate point phenomenon in a dynamic programming formulation of optimal control problems has been completed. The asymptotic behavior of the second partial derivatives of the optimal performance function near conjugate point singularity has been investigated using Hamilton-Jacobi Theory and certain matrix Ricatti type differential equation satisfied by these partial derivative The necessity of the Jacobi condition for optimality, which is a well-known result ir the calculus of variations, has been demonstrated for the dynamic programming formulation. A by-product of this study is the demonstration of the globally nonminmizing character of a relatively minimizing extremal whose end point is close enou to a particular type of conjugate point. Preliminary results have been published in JPL internal document.

STOCHASTIC OPTIMAL CONTROL THEORY

A paper describing the application of dynamic programming to a constrained form of the midcourse guidance problem appeared in the September 1965 AIAA Jour (Ref. 4). **A** JPL internal document describing an extension of Ref. 4 will be issued soon. In this formulation, we shall treat a performance index that is a function of two state variables at the final time, and develop the continuous form of the equatioi We will try to develop a computer program using this approach, which will be usefu for real-time and preflight mission analysis.

RELATIVITY THEORY

An investigation of the electromagnetic field caused by a uniformly accelerat electron has been made and will appear in JPL SPS 37-37, Vol. IV. Study of the meaning of "coordinate" time for a nonstatic expanding universe has been made. Tl misunderstanding of the meaning of coordinate time may be a main drawback to exis ing theories about an expanding universe.

COMPUTER SCIENCE

A straightforward application of the semianalytical method (Ref. 5) for solvi ordinary differential equations with polynomial representations has been made to th restricted three body problem. The results show that the number of derivative eval ations necessary for a given accuracy is of the same order of magnitude as with our latest double precision Cowell trajectory program. Various techniques will be usec to improve the present program, including a different choice of variables and techniques for accelerating convergence of series.

When Ref. 5 was submitted for publication, the referee (C. W. Clenshaw) made a comment on the extension of the method to second order differential equatio This has been pursued and applied to two point boundary value problems of the form $\ddot{x} = f(x, \dot{x}, t)$, $x(0) = C_I$, $x(T) = C_F$, where x is a vector, 0 and T are the initial and final times. The solution is made by collocation, or the choice of selected points, and by Picard iteration. The main contribution now is the optimal choice of selecte points. A program has been written and checked out to use this method. A paper is being prepared to describe the results. It is anticipated that the program may be successfully used in such areas as in finding ballistic trajectories that pass close to several planets.

Another approach to two point boundary value problems has been to a generalization of the Newton-Raphson method published in a JPL internal memorandum. This method is more general than the earlier method because the equations need not be second order.

Added research in the two-point boundary value problem has been made using a successive sweep method of solving optimal programming problems. This work is being prepared for publication of a Ph. D. thesis written under the supervision of Professor A. E. Bryson, Jr., of Harvard University (Ref. 6). This method is an elegant extension of second order gradient methods to problems with general constraints. It is now being extended to problems with state variable inequalities and it is planned to incorporate these extensions in an already successful computer program. An important by-product of this work is theoretical extension of the theory of optimal control.

Recently, some simple optimal control problems have been implemented on the IBM 1620 and 7094 computers using a dynamic programming computational approach. This was to gain some experience in the logistic and efficiency problems arising from computer storage, handling, and communication associated with the vast amount of data that this computational approach generates.

SEMINARS

In this reporting period, an extensive seminar was conducted at JPL on the subject of integral transforms and their engineering applications. Among the topics covered were the Laplace transform, the Fourier transform, the Hankel and Bessel transforms, difference equations and z-transforms, their interrelations operational properties, and some of their application to engineering problems. The seminar is continuing and yet to be covered are the Mellin, Hilbert, Abel and Legendre transforms, orthogonal series, and their applications.

A rather extensive series of lectures on probability and statistics, and their applications to the orbit determination program at JPL was conducted at JPL. The fundamental material covered is to be found in Ref. 7 and in unpublished notes by C. B. Solloway.

In July 1965, a series of lectures on probability, statistics, and orbit determination was delivered to the Summer Institute of Dynamical Astronomy, which was held at Stanford University. This Institute was jointly sponsored by Yale University, Stanford University, N. S. F., and NASA and conducted by the Department of Astronomy from Yale University under the leadership of Dr. D. Brouwer. The material covered was an extension of the material found in Ref. 7.

REFERENCES

1. Pfeiffer, C. G., "Sequential Estimation of Correlated Stochastic Variables," JPL TR 32-445, July 1, 1963.

2. Pfeiffer, C. G., "A New Approach to Optimal Final Value Control Theory," Journal of the Franklin Institute (to be published).

3. Pfeiffer, C. G., "A Technique for Optimal Final Value Control of Powered Flight Trajectories," AIAA Journal (to be published).

4. Pfeiffer, C. G., "A Dynamic Programming Analysis of Multiple Guidance Corrections of a Trajectory," AIAA Journal Vol. 3, No. 9, pp. 1674-1681, September, 1965.

5. Kizner, W., "Error Curves for Lanczos' Selected Points Method," JPL SPS 37-31, Vol. IV, 28 February 1965 (will also be published in the Computer Journal).

6. McReynolds, S. P., "A Successive Sweep Method for Solving Optimal Programming Problems," Ph. D. Thesis, Harvard University, 1965.

7. Solloway, C. B., "Elements of the Theory of Orbit Determination," JPL EPD 255 December 9, 1964.

JPL Technical Memorandum No. 33-272, Vol. II

LUNAR AND PLANETARY FLIGHT MECHANICS

NASA Work Unit 129-04-01-02-55
JPL 329-40201-1-3120

W. G. Melbourne

OBJECTIVE

The objectives are to conduct basic research in celestial mechanics, to evaluate astronomical and physical constants from postflight analysis of tracking data, to improve planetary ephemerides from radio tracking data and planetary radar data, and to study advanced techniques for trajectory calculation and the development of orbit determination capabilities that account more realistically for the physical features of the solar system and the spacecraft.

CELESTIAL MECHANICS RESEARCH

A set of computer programs for the three-body problem has been under development and is listed below.

An IBM 7094 program has been prepared to compute characteristic exponents of periodic orbits in the restricted three-body problem. Another program with the same characteristics has been adopted from a publication by A. Deprit. Characteristic exponents for 12 families of periodic orbits have been computed with this program. A regularized program (with Thiele variables) is being prepared for the computation of characteristic exponents. A program has been prepared for the computation of trajectories in the three-dimensional restricted three-body problem. A program has been prepared for the computation of trajectories in the restricted equilateral four-body problem, to study the properties of the equilateral equilibrium solution of the general three-body problem.

A program has been prepared for the computation of trajectories in the three-dimensional general three-body problem. The program exists now in two versions: in heliocentric and in barycentric coordinates.

A program similar to this one, but using a power series solution, is being prepared. The program is in heliocentric coordinates, and mainly designed for the integration of two planets around the Sun.

A program for the integration of the elliptic restricted three-body problem is now being prepared.

A program for the study of Stiefel variables in the perturbed two-body problem has been prepared.

A program for the study of the Pitkin-regularization of the perturbed two-body problem has been prepared.

Several regularization studies in the three-body problem have been conducted. These have been published in a JPL internal document and Refs. 1 and 2. Reference 2 will be presented at the AIAA winter meeting in New York in January 1966.

A more accurate set of equations of motion for the computation of the librations of the Moon were derived for the Moon considered as a triaxial ellipsoid. Approximations and truncations in formulas and planetary and lunar theory were avoided when published as JPL internal document. The resulting sixth order system of differential equations was prepared for numerical solution using the JPL ephemeris tape for the determination of the acting perturbing forces. Preliminary results of the computer solution show the utility of this approach is limited by our present inability to accurately prescribe initial conditions.

An extensive documentation and review has been conducted of the open literature on the various perturbation techniques and sets of variables used. The results of this work are in a JPL unpublished literature search.

A survey paper (Ref. 3), was prepared for publication through the American Astronautical Society (AAS) and was presented at the AAS meeting, "Recent Developments in Space Flight Mechanics," on December 29, 1965, in Berkeley, California.

ASTRODYNAMICAL AND PHYSICAL CONSTANTS

The forthcoming introduction of the DPODP coupled with increased capabilities of the DSIF stimulated investigation of the effect of the interplanetary medium on DSN inherent accuracy. A study was begun into the possibilities of examining the results of the radio propagation experiment aboard the Pioneer spacecraft to try to find out whether the phase path effects of charged particles along the radio tracking signal ray path can be effectively measured (a JPL internal document was published on this study). Close cooperation between the Stanford University experimenters and JPL is being encouraged. A proposal (Ref. 4) has been made calling for coordination of their findings and the JPL orbit determination results. We plan to investigate the possibilities of using dual frequency radio tracking for all spacecraft whose orbit determination requirements are limited by the uncertainties in the phase path caused by the presence of charged particles in the regions of the ionosphere and the interplanetary medium through which the tracking signals propagate.

A preliminary study to investigate the feasibility of determining the masses of the Earth and Moon, the AU, and the Earth's ephemeris from the tracking of Pioneer probes was started in October. A publication of the significant results is in preparation. These studies have shown that a dramatic improvement in accuracy up to two orders of magnitude in certain orbital elements of the Earth can be obtained from radio tracking data of the Pioneer probe taken over 1 yr. Table 1 shows the improvement in several parameters for 6 mo and for 1 yr of DSIF doppler data from a hypothetical Pioneer space probe. The orbit has a perihelion distance of 0.83 astronomical units and is inclined $0\overset{\circ}{.}036$ to the ecliptic. The parameter GM in the table is the lunar gravitational constant.

Table 1. Standard deviations of several parameters obtainable from Pioneer tracking data

Parameter	A priori error (no tracking)	6 mo tracking	1 yr tracking
Probe position (km)	∞	0.8	0.1
Probe velocity (m/sec)	∞	0.7	0.2
GM (km^3/sec^2)	1.0	0.0090	0.0056
Eccentricity of Earth's orbit	0.5×10^{-6}	0.53×10^{-7}	0.33×10^{-8}
Obliquity of the ecliptic	$0.''1$	$0.''050$	$0.''012$
Astronomical unit (km)	500	77	4.4

As a result of this work the proposal mentioned above was prepared.

Preliminary analysis of the accuracy of determining the orbit of a Martian orbiter from DSIF tracking data has been performed. Also, the feasibility of improving existing knowledge of the Martian gravity field and ephemeris and the astronomic unit (AU) have been investigated. Figure 1 shows the expected improvement in the principal second-order harmonics, $J = 3/2\ J_2$ and $L = 3C_{22}$, as a function of tracking duration. The orbit about Mars has periapsis and apoapsis altitudes of 2000 and 35, 000 km, respectively, and is not the most favorable for a determination of the gravity field. A proposal (Ref. 5) has been prepared and submitted in November to the Director, Grants and Research Contractor, Code SC, NASA, Washington, D. C.

PLANETARY EPHEMERIDES IMPROVEMENT

As the mission requirements of our space program become more exacting in the coming years, it will be necessary to improve the accuracy of existing planetary ephemerides. Ephemeris improvement studies are planned using more accurate estimates of certain astronomical constants obtained from radio tracking of space flights, from recent planetary radar-bounce data, and from optical data taken by astronomical observations. This work will proceed in close communication with the U. S. Naval Observatory, and its utility to the International Astronomical Union in establishing an international ephemerides is a long-term goal.

Some preliminary technical studies of n-body integration and statistical combination procedures have been made.

An analytical solution of the n-body problem in the form of power series has been prepared. The classical JPL ephemeris has been checked for the 9 planets and the Moon all together, on 100 points at 10-day intervals. The maximum deviations are of one unit in the sixth significant digit. This probably leads us to the conclusion that at least one body on the ephemeris tape has a relative error of one unit in the sixth significant digit. A program has been prepared to compute the four first integrals of an n-body solution stored on an ephemeris tape. A simultaneous integration on the IBM 7094 of the 9 planets and the Moon has been done over 50 days, using an integration step of 1 day and keeping 15 terms in the power slides. The precision, as checked with the energy and angular momentum integrals, is 14 places. The running time is 10 sec per step. However, it remains to optimize the running time of the program particularly with respect to required precision. For comparison, typical ordinary numerical integration methods with a precision of 12 places require a running time of 2.5 sec per step. A program has been prepared to solve by Cowell integration the N-M-planet problem (integration of N planets perturbed by M planets with a known ephemeris stored on magnetic tape).

To integrate easily the preceding trajectory-problems, a general purpose differential equation integration subroutine has been prepared. This subroutine uses the Adams-Moulton method with a table of up to 16 differences.

A weighted least-square package (with given a priori solution and corresponding covariance matrix) has been prepared for the IBM 7094. This package has been tested out on the construction and solution of the normal equations in Rabe's Eros problem, and gives the correct results.

A most important result obtained concerns the Earth-Moon barycenter ephemeris. An analytical study showed that separated Earth-Moon masses would produce a barycenter about 3 km larger in radius and 0.6 mm/sec greater in velocity than the current JPL ephemeris, which assumes combined masses. These effects are observable with current radio tracking accuracies and degrade the quality of the orbit determination process. This discrepancy will be corrected in future ephemerides.

SELENODESY

The principal support for this task area is from OSSA for the Lunar Orbiter Selenodesy Gravity Experiment (SGX). However, the Flight Mechanics task continues to support the basic research fundamental to this activity. A JPL internal memorandum gives a summary of certain formulas and relations among the equations of motion in averaged variables. Another JPL internal memorandum contains reviews requested by NASA Headquarters of several proposals for lunar orbiter studies. A third JPL internal memorandum summarizes the study effort for SGX and describes the computer program development underway.

An article titled, "Long Term Behavior of Artificial Satellite Orbits Due to Third Body Perturbations," by J. Lorell has been submitted and accepted by the Journal of the Astronautical Sciences.

A new formulation of indirect Earth-Moon oblateness acceleration was described in a fourth JPL internal memorandum.

ADVANCED TRAJECTORIES

Some high-energy, round-trip Earth-Mars trajectories are described in Ref. 6.

An analysis has been completed for obtaining performance estimates from asymptotically matching two-body planetocentric and heliocentric low-thrust trajectories. The technique is called the asymptotic velocity intercept method and is applicable to the case of a spacecraft under constant thrust with finite propellant losses. Both planetocentric spiral trajectories starting from a circular orbit and planetocentric trajectories with initial parabolic and hyperbolic energy conditions have been considered. These results have been submitted to the AIAA Journal and appear in Ref. 7.

SEMINARS

For a 6-wk period during July — August, one staff member was an attendee at the Summer Institute in Dynamical Astronomy at Stanford University.

The series of monthly astrodynamics seminars under the auspices of the American Astrodynamics Society, first held at JPL in June, was again hosted by JPL in September and December. These sessions continue to serve as a vehicle for communication between engineers and researchers in the field of astrodynamics in Los Angeles-San Diego area.

Members of our technical staff have attended four technical society meetings: (1) AIAA National Meeting, San Francisco, July 26 – 29, 1965; (2) Astrodynamics Specialists Meeting (AIAA), Monterey, September 16 – 17, 1965; (3) AAS Meeting on Bound Orbits of Remote Primaries, Seattle, December 2 – 3, 1965; and (4) AAAS-AAS Meeting on Recent Developments in Space Flight Mechanics, Berkeley, December 29, 1965.

Mr. Lorell was directly concerned with the organization and running of the two AAS meetings as chairman of the National Technical Committee on Space Flight Mechanics. He presented a paper at the Seattle Meeting titled, "A Computer Program for Using a Lunar Orbiter to Evaluate the Moon's Gravity Field." He chaired the afternoon session of the Berkeley meeting.

REFERENCES

1. Broucke, R., "Symmetrization of the Two-Body Problem," JPL SPS 37-33, Vol. IV, June 30, 1965, p. 23 – 28.

2. Broucke, R., "Regularization of Non-Conservative Systems," JPL SPS 37-34, Vol. IV, August 31, p. 11 – 15.

3. Anderson, J. D., "Trajectory Determination from Observational Data," Presented at the AAAS Meetings, December 29, 1965, Berkeley, California.

4. Anderson, J. D., Efron, L., Warner, M. R., "Preliminary Proposal for a Primary Determination of the Masses of the Earth and Moon, the Astronomical Unit and the Ephemeris of the Earth from the Pioneer Tracking Data," November 1, 1965.

5. Anderson, J. D., Warner, M. R., "A Proposal for Precise Determination of Gravitational and Dynamical Parameters of Mars Using Tracking Data from the Voyager Orbiter," November 1965.

6. Dallas, S. S., "High-Energy Earth to Mars and Return Trajectories," JPL SPS 37-34, Vol. IV, August 31, 1965.

7. Melbourne, W. G., Sauer, C. G., Jr., "On Performance Computations with Pieced Solutions of Planetocentric and Heliocentric Low Thrust Trajectories," JPL SPS 37-36, Vol. IV.

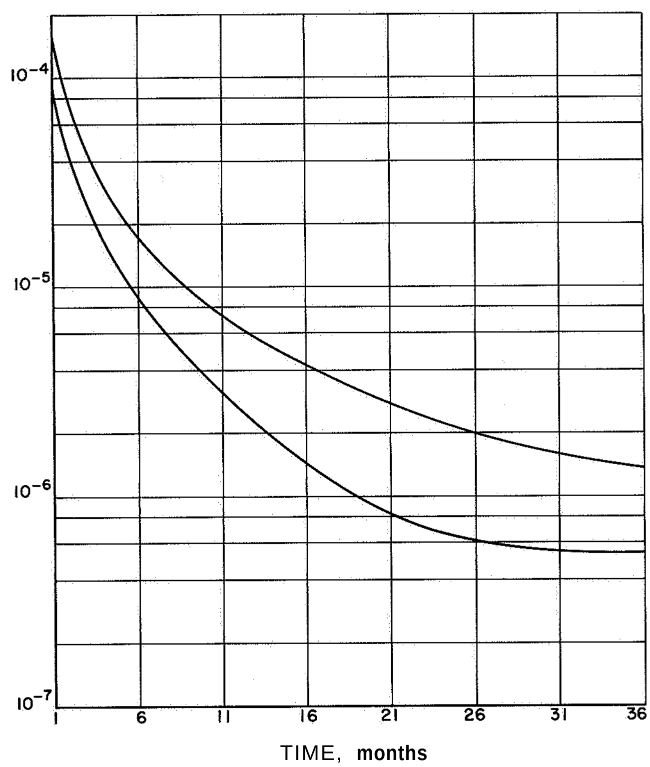


Fig. 1. Accuracy of determination of J and L as function of mission duration

NUMERICAL ANALYSIS

NASA Work Unit 129-04-04-01-55
JPL 329-40301-1-3140

Robert J. Jirka

OBJECTIVE

The basic objective of this work unit is to develop and analyze general computer-oriented algorithms.

ACTIVITIES

During the past half-year (January — June 1965) a computer subroutine CONTUR was designed and programmed for plotting contour graphs for any function z = f(x, y) whose values are known or can be computed at the lattice points of a rectangular grid (JPL SPS 37-32, Vol. IV, pp. 18-22). The subroutine CONTUR was designed for general purpose utility so that it would be convenient for JPL engineers to obtain this type of graphic output in connection with differing applications.

During the current half-year (July — December 1965) JPL engineers working in three diverse fields have used CONTUR. These applications were (1) analysis of deformations of the Goldstone parabolic antennas, (2) analysis of Ranger photographic data, and (3) analysis of energy launch data for mission planning. CONTUR has been improved to permit the region of interest to have irregular boundaries. A lecture on the CONTUR algorithm was given at the University of Texas Computation Center (December 7, 1965).

Preliminary work was done on the problem of superimposing a triangular grid on an aribtrary irregularly arranged finite set of points in a plane (JPL SPS 37-35, Vol. IV, pp. 24-26). This work relates to the problem of producing a contour graph for a function whose values are known only at such a set of points.

A Boltzmann partial integro-differential transport equation of high dimension has been simplified so that a gain in computer machine time on the order of 100 should be possible compared with earlier attempts. The method of reduction consists in deriving a Kernel that can be computed independently from the iterations and reduces the successive approximations to table pickups only. Implicit differentiation is being used to facilitate computation of the Kernel tape. Besides its mathematical properties, which also permit improved control of numerically ill-conditioned difference terms, the kernel lends itself to an interesting physical interpretation.

CELESTIAL MECHANICS

NASA Work Unit 129-04-04-02-55
JPL 329-40401-1-3140

Robert J. Jirka

OBJECTIVE

The objective of this work unit is the development and analysis of methods for the prediction of the motion of natural and artificial bodies in the solar system. Specifically, this concerns an improvement of the predictions of the inner planets using corrections derived from the reduction of planetary radar observations and the development of more accurate general perturbation theories for planetary motion.

ACTIVITIES

The primary activity under this work unit is the continuing development of the JPL planetary and lunar ephemerides. These ephemerides are tables giving the position and velocity of each planet and the Moon, and the nutations in longitude and latitude with their time-derivatives as functions of ephemeris time.

In producing the JPL ephemeris (JPL TM 33-167) by numerical integration, the Earth-Moon system was treated as a single point-mass located at the barycenter of the Earth-Moon system. Using numerical integration, studies have been made on the effect of using a more precise model (i.e., a different system of differential equations) in which the Earth-Moon system is replaced by a two-point system. This will be referred to as the "Earth-Moon-separated" model. The location of the Moon relative to the Earth is still computed from the Improved Brown Lunar Theory, as previously.

Both the earlier model and the Earth-Moon-separated model were fitted to an ephemeris of the Earth-Moon barycenter computed at JPL from Newcomb's theory. These fits were computed over an 18.5-yr interval beginning at January 1950 using the Planetary Orbit Determination program PLOD (JPL TM 33-188). For both models, the maximum difference in rectangular coordinates between the fitted ephemeris and the Newcomb ephemeris was 5.4×10^{-7} AU. The maximum difference between the two (different) fitted ephemerides was 1.0×10^{-7} AU in rectangular coordinates and 1.8×10^{-9} AU per day in rectangular velocity coordinates. Graphs showing the structure of these residual curves are included with the report of this study in JPL SPS 37-36, Vol. IV.

Tables of the maximum ratio of perturbing forces to solar attraction were computed for each ordered pair of planets and reported in JPL SPS 37-34, Vol. IV. An harmonic analysis of residual curves of the integrated ephemerides of the outer planets was reported in JPL TM 33-244.

The double-precision computer program RADAR 1 (which is used to compute predictions of range, doppler, and angular coordinates for JPL lunar and planetary radar experiments) was also used to compute such predictions for the Naval Research Laboratory, Washington, D. C., for the period surrounding the January 1966 inferior conjunction of Venus.

Dr. W. J. Eckert of Watson Scientific Laboratories has recently computed improved values for the parallax coefficients in the Improved Brown Lunar Theory. Work has been started to incorporate these into the JPL lunar ephemeris.

Planning is under way to make use of classical optical observations to further improve the JPL ephemerides. This work will be coordinated with work at the U. S. Naval Observatory and the Yale University Observatory. It is anticipated that this work will involve the lease of time on a computer larger than those now available at JPL and the use of two more contract computer programmers.